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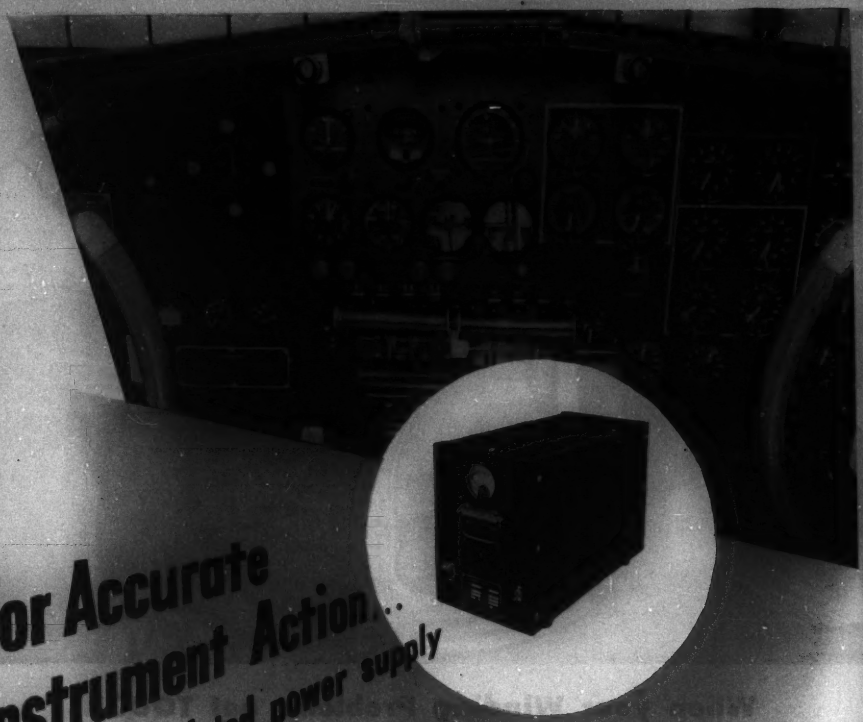

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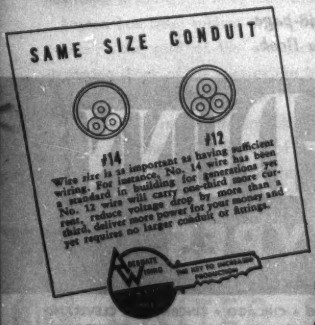
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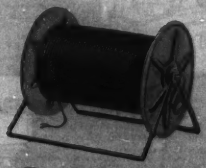

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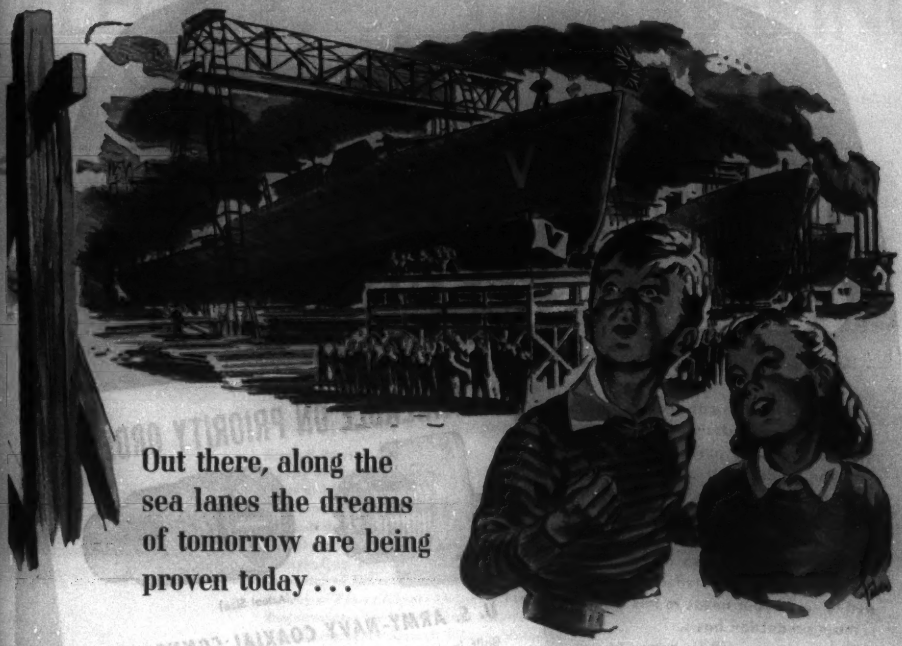

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ELECTRICAL ENGINEERING
VOLUME 63, NUMBER 11 NOVEMBER 1944

Retain Germany's Peacetime Industry!

Urge Presidents of Five National Engineering Societies

Declaring that the proposed destruction of Germany's entire industrial plant is economically unsound and contains the seeds of a new war, the presidents of the American societies of civil, mining and metallurgical, mechanical, electrical, and chemical engineers, in a jointly signed statement recently released to the press, urge that only that part of German industry devoted to armament be destroyed. Although prepared specifically as a criticism of Secretary of the Treasury Henry Morgenthau's proposal of a wholly agricultural postwar economy for Germany, it is an equally apt criticism of all proposals calling for indiscriminate destruction of the German industrial economy. Full text of the statement is presented here. The presidents of these societies also are taking steps through appropriate channels toward assuring that engineering advice be brought to bear on peace problems.

ON the basis of our experience in engineering and industry, we consider that the proposal of the Secretary of the Treasury for the control of postwar Germany by the destruction or virtual dissolution of her industrial plant is economically unsound and contains the seeds of a new war. We believe that the part played by over 75,000 members of these societies in the design, engineering and production of the implements for our Armed Forces in quantities adequate for Victory, as well as our long experience as engineering industrialists in peacetime, entitle us to speak on this subject of paramount importance to the peace of the world.

In general, the Morgenthau proposal is indefensible because the destruction of the machines, utilities, tools, materials, and other essentials for peacetime living penalizes not only the owners of the materials destroyed, but the world as a whole. Specifically, the fundamental fallacy of the proposal for the indiscriminate destruction of the German industrial system is that it fails to differentiate between the wartime and the peacetime economy of the Reich.

We are for one simple, clear objective—an effective industrial means to keep Germany from starting another war. This objective should not be confused, especially before the war is even won, with the appropriate punishment of Germany or with the international arrangements for the long future to be made around the peace table by the representatives of the Allied Nations after victory is achieved. This statement, therefore, deals not with broad, complex, postwar questions of diplomacy and international policy, but simply and solely with the suggestion for the indiscriminate dismemberment of the German industrial economy.

"Unconditional surrender" implies disarmament of the German armies, the surrender of all arms, munitions, airplanes, and other ordnance matériel in stock piles or in process. It also should include the elimination of all German war production facilities such as aircraft plants, munitions plants, and submarine works, and the control of raw materials required by war industries.

We make no suggestions as to the overall international treatment of Germany after surrender, but confine our statement to the physical disarmament of Germany and to the subsequent steps to make it impossible for her to prepare industrially for another war. With this sole aim in view, however, we must recognize that the German nation cannot arbitrarily be kept in economic and industrial subjugation. To do so would create an economic vacuum in Europe which sooner or later would be filled, either by the German nation itself or by the collaboration of Germany with other nations or individuals who would profit financially or politically, or both, by helping to develop Germany into a good market.

Germany must have its chance for recovery along peaceful lines after the war. Such recovery cannot come about through an economy wholly agricultural, even if that were practicable; or without industry to produce both for German needs and for the reconstruction of other nations of Europe; or without markets.

It is farthest from any suggestion of a so-called "soft peace" to recognize this fact. Germany must be disarmed and that part of its industrial plant devoted to armament destroyed. But it is equally necessary to create a plan which will (*a*) allow the German people to live a reasonably normal life; (*b*) permit the retention of German industry to help in the vast task of restitution and reconstruction, and (*c*) keep an economic balance in Europe. This, we are confident, can be done without giving German industry the independence it would require to prepare for war again, either secretly or overtly.

We recommend, therefore, not an indiscriminate destruction, but a selective restriction and control of German industry. Germany and Europe and the world need the contributions which the German nation, freed from the domination of war lords, can make in the future, as it has made in the past, to the development of modern technology and scientific and industrial advance.

If allied controls force the German people into an unnatural existence and hold back national economic development in Europe, they will become even more unstable and subject to pressures and possibilities containing the explosive seeds of another war. We should plan, therefore, to create a minimum of controls and to avoid abnormal social dislocations.

Discriminating between peace and war economy, there are at least six industries which are the most essential for war purposes, and the least essential for a peacetime economy. They are: synthetic gasoline, for which there is no economical peacetime use; manufacture of explosives; airplane production; use of aluminum and magnesium; high alloy and electrolytic steels; and nitrogen fixation, all of which must be vastly expanded to prepare for war. The labor employed by all these six industries in peacetime is less than two per cent of the total German labor force.

Therefore, Germany's capacity to make war would be eliminated by the following steps in regard to its industrial economy:

1. Eliminate all synthetic-oil capacity and prohibit the reconstruction of plants and the importation of oil beyond normal peacetime in-

ventories. This would destroy the major part of Germany's internal oil resources. Coal is the raw material for synthetic oil. It is plentiful in Germany and only a small per cent is used in synthetic-oil plants. It is not readily controllable in the Reich.

2. Eliminate 75 per cent of Germany's synthetic-nitrogen plant capacity and prohibit reconstruction of plants and all importation of nitrogen compounds. This will leave a capacity in Germany ample for peacetime nitrogen requirements. The principal ingredient of explosives is nitrogen. The relatively small amount of dynamite required for mining, quarrying, and so forth, should be under import control.

3. Eliminate 50 per cent of Germany's steelmaking capacity in those categories of plants which are most capable of producing essential war materials such as heavy forgings, electrolytic and high alloy steels. Manganese, chromium, nickel, and tungsten are practically nonexistent in Germany. Also prohibit importation of iron ore, flux material, steel, and steel products beyond normal peacetime inventories.

4. Eliminate aircraft plants and equipment. Aluminum and magnesium are the raw materials required for airplane manufacture. There are no important bauxite deposits in Germany. Importation should be prohibited. Aluminum and aluminum plants should be destroyed and importation of aluminum ingots beyond prewar peacetime needs be prohibited.

If any *one* of these steps were taken, war could not be waged nor prepared for. Taking all four would afford ample insurance against war.

By attacking the problem from this angle, it would be possible to set up uncomplicated, nonpolitical controls to prevent the rearmament of Germany, but at the same time make it possible for the German nation to meet its own peacetime needs and thereby prevent her from becoming a drag on the economy of all Europe and a breeder of future wars.

Fifty or 60 per cent of the German oil and gasoline supplies have come from synthetic-coal distillation plants scattered throughout Germany. A third of her requirements has been derived from the Ploesti oil field in Rumania. The synthetic plants produce inferior products at a cost about four times world prices. Their operation has required Government subsidy. These war plants should be demolished.

Eighty per cent of nitrogen is produced synthetically from the air, but it could not be produced without reconstruction of special plants or without Chilean nitrates which Germany must import. Germany could not make steel, produce oil products, or make munitions of war without imports of bulky easy-to-police materials. Hence policing the curtailment of potential war production would consist of: (*a*) controlling the imports of, or the accumulation of stocks of, such bulk materials as petroleum, pyrites, or brimstone, manganese, chrome ore and iron ore, steel, aluminum, and nitrogen compounds; and (*b*) requiring periodic inspections of plants and special revocable permits of construction or of operation of manufacturing facilities for any purpose. Further insurance could be secured by transferring the ownership or management of nitrogen and steel production plants into allied hands.

Under such a plan Germany still could re-establish a productive economy for nonmilitary purposes. It would leave Germany economically free to expand along peaceful lines, and give her a competitive position in international commerce with other nations burdened with high debt charges, the maintenance of armies and navies, rehabilitation costs, and so forth.

A large part of the determined peacetime productive capacity of Germany should be turned immediately, and for a long period, to the manufacture of restitution materials for war-damaged countries. The percentage of industry turned to this purpose should be the maximum possible without reducing the people to a submarginal level.

When the Allied Nations presently have rendered Germany harmless by disarmament for the next 10 or 15 years, a program of permanently disarming her must look not to 15 but to 50 years. It is unrealistic to assume that any program put forward to take the sting out of Germany will not require supervision and vigilance for a long period in the future.

The essence of this program is to remove from Germany the plant and source materials essential for war purposes, but to do it with the least disturbance to the normal economy of Western Europe.

Engineers play an essential part in providing employment in the economy of any nation. In this country especially they see their function not in narrow, professional terms, but in providing jobs and in promoting industrial production. They do not believe that crippling the normal peacetime industrial economy of any country, even an enemy nation, can promote world peace and reconstruction. On the contrary, such a policy jeopardizes the peace and progress of all. We are opposed to any plan which would make postwar Germany a drag on the economy of all Europe, if not of the world, and a breeder of future wars.

MALCOLM PIRNIE, President, American Society of Civil Engineers

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Wind-Tunnel Testing

This giant wind tunnel for testing full-size airplanes under simulated conditions, built and operated by the National Advisory Committee on Aeronautics in Ames Aeronautical Laboratory, Moffett Field, Calif., contains six 6,000-horsepower Westinghouse motors. Each of the 57-ton motors drives a six-bladed spruce fan 40 feet in diameter. As shown, the motors are mounted in two horizontal rows of three in a 90- by 128-foot portion of the tunnel. Center line of the top row of motors is about 90 feet above ground level. The basic purpose for the Ames Laboratory wind tunnel is to enable the designing and building of faster, safer, and more efficient aircraft. The test section of the tunnel is 80 feet wide and 40 feet high, thus allowing for the testing of full-size airplanes, including some of the two-engine type. The major problem for solution by wind-tunnel testing deals with reducing the effect of forces which impede forward motion of an airplane.

Efficient Operation of Hydroelectric Systems

L. B. STIRLING
ASSOCIATE AIEE

J. M. SHARPE
ASSOCIATE AIEE

THE PROBLEM of efficient operation of hydroelectric systems is one which must be familiar to all engineers engaged in the operation of such power systems, but it does not appear to be given very much attention in the technical press or other publications. One sees frequent mention of the high efficiency of steam-electric stations, generally given to the second or third decimal place, and the loading schedules for such stations usually are based on a detailed analysis of incremental costs. Descriptions of hydroelectric plants, however, are generally limited to the size of the units and spectacular details of the construction.

This situation with regard to hydroelectric stations probably has arisen from the fact that the problem of operating several hydroelectric plants at best over-all efficiency is much more complex than the parallel problem with steam plants. In the first place the source of energy is seldom under close control and is subject to unexpected variations. In addition, this potential energy seldom can be stored in quantity within a short distance of the point of use. With coal-burning plants, if it is found that a certain block of electric power can be produced by burning nine tons of coal at one plant or ten tons at another, the obvious solution is to burn the nine tons and leave the ten on the coal pile of the second plant. In the case of hydroelectric plants, the study must be carried further to determine whether the ten tons will remain on the pile until such time as they can be used to advantage.

No matter what the arrangement of the system may be, it is obvious that the first requirement for efficient operation is to determine the characteristics of each individual generating station. In the past, some hydroelectric-system operators probably have been deterred from checking the characteristics of their prime movers by the apparent difficulty and cost of measuring large flows of water with a reasonable degree of accuracy. As a matter of fact, when these flows are confined to regular passages such as intakes and penstocks of turbines, their measurement seldom is difficult, and the cost generally is insignificant compared with the value of the information which may be obtained.

THREE METHODS OF FLOW MEASUREMENT

There are three widely accepted methods of flow measurement used in North America for the determination of turbine discharge and, generally speaking, each one is particularly suited to one certain type of installation. The salt velocity method, developed by C. M. Allen of Worcester Polytechnic Institute, is based

The careful testing of each generating unit and the setting up of loading schedules similar to those commonly used on steam-electric systems will pay generous dividends in efficiency of operation of a hydroelectric system, these authors conclude from their experience with the system described in this article.

on the time required for a charge of electrolyte, injected into the stream, to pass from one set of electrodes to another set further downstream in a well-defined water passage. Obviously, the electrodes must be far enough apart to give a time interval which can be measured readily with a fair degree of accuracy. The installation of the electrodes and electrolyte-injection equipment generally requires a shutdown of the unit for a number of hours or even days, but the test can be conducted without causing any noticeable system disturbances. It is an empirical method, and some experience in interpreting the test data is necessary to insure accurate results.

Figure 1 is a reproduction of a section of a salt velocity record. The arrival of the salt solution at the upper and lower electrodes is indicated clearly, and the elapsed time is measured by means of the dots at the upper edge of the chart. Figure 2 illustrates an installation which can be tested most readily by means of the salt velocity method. The intake tunnel is long enough to give adequate intervals, and the test electrodes can be installed readily in the level sections.

The Gibson method developed by Norman Gibson of the Niagara Falls Power Company, is based on the measurement of the energy contained in a well-defined section of the stream. When the flow is arrested at the outlet, the product of the pressure rise which occurs and the time during which it is present is a function of the original energy in the stream. This method provides a means of recording and measuring this product of pressure and time and, when the dimensions of the conduit have been determined, the velocity of the stream may be calculated readily from these data. The installation of the test equipment frequently can be made without shutting down the unit, but the actual testing may cause serious voltage and frequency disturbances, unless the system is large enough to absorb the sudden loss of output of the unit.

A typical record of a Gibson test is shown in Figure 3. The energy of the stream is represented by the dark area above the line *OML* in which vertical distances are proportional to pressure and horizontal distances to time. Figure 4 illustrates a type of station to which the Gibson method is particularly applicable. The necessary piezometers were installed during the construction of the plant, and tests now can be made with very little preparation and at a negligible cost.

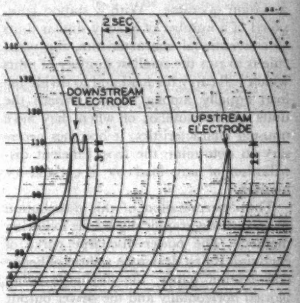

Figure 1. Salt velocity chart

The "current-meter method" was developed in Europe and has gained favor in Canada only in the last few years. It consists of measuring the velocity at numerous points at some section of the water passage, generally the intake, and combining these measurements to find the average velocity of the whole stream. Generally the equipment can be installed and the test carried out without any interference with operation, but the metering section must be so located that the flow is reasonably streamlined, and is not far from normal to the metering section.

A portion of the record chart of a current-meter test is shown in Figure 5. In this case nine meters were in operation simultaneously, the tenth trace being a record of elapsed time. This method is generally best adapted to the testing of low-head installations such as that shown in Figure 6 where the intake passages are generally too large and short for the economical application of other testing methods.

The data obtained from any efficiency

Essential substance of a paper presented before the AIEE Montreal Section, Montreal, Quebec, Canada, May 5, 1944.

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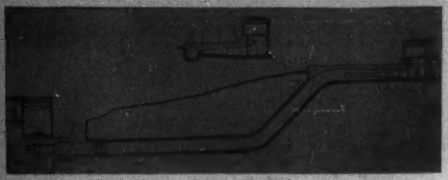


Figure 2. Unit 6–2, Shawinigan Falls

Figure 3. Gibson chart

test of a unit are generally arranged as shown by the curves in Figure 7. These give all the information necessary to plan an efficient loading schedule, but they do not show it in suitable form for the use of a station operator. With a station composed of a number of exactly similar units of conventional characteristics, the usual rule is to run the smallest number of units which will carry the load and to divide the load equally among them. Where the units are not similar, or when they have unusual characteristics, it becomes necessary to determine the most efficient distribution of any load by a cut-and-try method.

The determination of this distribution may be made graphically by the following method: The power–discharge curve of each unit is first drawn on a sheet of heavy cross-section paper, the discharge being plotted horizontally and the power output vertically. These sheets then are cut along the plotted curves to form templates. One template is inverted and fastened to a drawing table in this position. A second template, in the upright position, is laid over it with the bottom edge resting against a T square, as shown in Figure 8. In this position each abscissa represents a definite output, and its length is proportional to the corresponding discharge. As one template is inverted, the sum of the outputs represented by any two abscissae which coincide in a constant. Thus, the loose template is moved vertically until the sum of any two abscissae which coincide equals the total load under consideration, as, 38 kw in Figure 8. Their total length is proportional to the discharge, but this will vary with the distribution of the load. To find the minimum discharge, the loose template is now moved along the T square until a common tangent point of the two curves just appears. The two abscissae which coincide at this tangent represent the most efficient distribution of the load under consideration.

This procedure is repeated for all loads between the capacity of one and two units, and with different combinations of units.

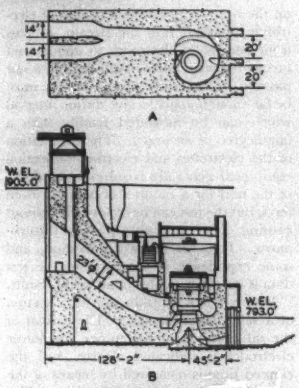


Figure 4. Rapide Blanc power-house unit, 44,400 horsepower

A. Plan at center line of penstock
B. Section through unit

When the most efficient combination of two units, within practical limitations, has been determined, a power–discharge template for two units is made up and the same procedure repeated to find the loading schedule for three units. Eventually the most efficient division of any load is determined and may be plotted as a graph for the guidance of the station operators. A station power–discharge curve also may be made up from these data, and these two curves, together with information on the maximum permissible forebay elevation, will enable an operator to load his station in the most efficient manner.

It is advisable, however, to provide some means of checking the daily operation to determine whether the maximum output has been realized, or whether the customary standard of efficiency is being maintained. One could do this by checking the conditions as recorded on the log sheet hour by hour, but this is extremely laborious and does not give a simple over-all picture of the situation. A better method is to predetermine from the test data and other relevant information the maximum daily output which can be obtained from any river flow and to compare the actual output with this theoretical maximum.

In order to determine this maximum output, the first requirement is to find the maximum head available at any flow. The permissible forebay elevation generally varies with the flow and the tailrace rises as the flow increases, the usual result being that the available head decreases very appreciably at high flows.

It then is assumed that the station can be operated at the peaks of the station efficiency curve only, that is, the average intermediate loads may be carried by operating part of the time at the higher efficiency peak and part at the lower one. With this assumption the station efficiency curve may be taken to be the envelope of the true efficiency curve, and the station discharge as the envelope of the true discharge curve. To determine the maximum output for any station discharge, the first step is to find the head corresponding to that discharge. The portion of the total flow which consists of unit discharges is then found, and the corresponding discharge at the head on which the station discharge curve is based is calculated. This point is located on the discharge envelope, and the corresponding efficiency is determined from the efficiency envelope. When the total unit discharge, the head, and the efficiency are known, the output is readily calculated, and a curve showing the maximum daily output for any station discharge can be made up.

The difference between the maximum and the obtained outputs is the loss due to inefficient operation and, for purposes

Table I

Time	Station Load—Megawatts	Station Discharge—Cubic Feet Per Second	Headrace Elevation
1 a.m.	55.0	11,870	101.2
2	55.0	11,870	101.3
3	55.5	11,835	101.6
4	56.0	11,900	102.0
5	57.0	11,920	102.5
6	57.5	12,010	102.9
7	83.0	17,950	103.3
8	103.0	22,860	103.1
9	104.0	23,040	102.9
10	104.0	23,040	102.8
11	104.0	23,040	102.6
12 N.	103.0	23,215	102.5
1	78.0	18,120	102.9
2	103.5	23,385	102.6
3	103.5	23,385	102.6
4	102.0	22,945	102.5
5	102.0	22,945	102.4
6	102.0	22,945	102.2
7	102.0	22,945	102.0
8	101.0	22,945	101.9
9	101.0	22,945	101.7
10	100.0	23,125	101.5
11	76.0	16,950	101.5
12 M.	77.5	17,410	101.8
Total 2,085.5 megawatts Average		19,297	102.2

of comparison, may be expressed as a percentage. This loss, however, can be broken down readily into the loss due to low head and the loss due to improper loading.

From Table I,

Total power generated from hourly readings = 2,085.5 megawatt-hours.
Total generated from integrating watt-hour meters = 2,090.0 megawatt-hours.
Corrected average discharge = $19,297 \times \frac{2,090.0}{2,085.5} = 19,423$ cubic feet per second.
Maximum daily output at 19,423 cubic feet per second with headrace elevation at 102.7 = 2,130
Total generated power = 2,090.
Loss = 40.0 megawatt-hours
Maximum head for discharge of 19,423 cubic feet per second = 60.1 feet
Loss in headrace = 102.7 − 102.2 = 0.5 foot.
Loss due to reduced headrace elevation $= 0.5 \times \frac{2,130}{60.1} = 17.7$ megawatt-hours
Loss due to improper loading = 40.0 − 17.7 = 22.3

The difference between the maximum head, as shown by the curve, and the average daily head is determined, and the maximum output is multiplied by the ratio of this difference to the maximum head. This gives the loss due to low head. The remainder of the loss accordingly must be due to improper loading. It would be possible to break this down further into losses due to frequency control, maintaining spare capacity, and so on, but this would involve a good deal of clerical work and would probably call for additional personnel. The simple breakdown shown herein has been found to be quite satisfactory and can be calculated readily by the normal operating staff.

EFFICIENT OPERATION OF GENERATING SYSTEMS

The foregoing relates to the efficient operation of individual stations. When a number of generating stations are operated together, additional factors have to be considered. The following outlines certain practices which are employed by the Shawinigan Water and Power Company in order to maintain maximum operating efficiencies. It is appreciated that these procedures are not applicable necessarily to all systems since hydroelectric systems differ from one another as black differs from white. What is good practice on one system may be poor practice on another, and what is essential in some cases may be useless under different circumstances.

On systems where both steam- and hydroelectric generation are employed, and particularly where hydroelectric is only a small part of the total capacity, the control of the hydroelectric generation is not so difficult as when the total power supply is from hydroelectric stations. The conditions on the Shawinigan system especially are complicated, because the main generating stations all are located one above the other on the same river—the St. Maurice.

Figure 12 shows the relative locations of the stations. The principal characteristics of this system, as far as the subject of this paper is concerned, are as follows:

1. There are ten power sites on this river with a potential capacity of 2,000,000 horsepower. Of these, five sites, with an output of over 1,100,000 horsepower have been developed.

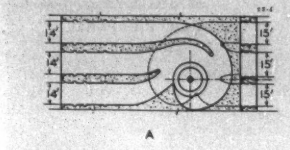
2. The La Gabelle, Shawinigan, and Grand-'Mere stations, with a total capacity of approximately 700,000 horsepower are located within 30 miles of Three Rivers where the St. Maurice discharges into the St. Lawrence.

3. The Rapide Blanc and La Tuque developments, with a total capacity of 422,500 horsepower are located about 100 miles north of Shawinigan Falls.

4. Out of a total drainage area of 15,400 square miles, 6,077 square miles are controlled completely or partially by storage reservoirs with a capacity of over 350,000,000,000 cubic feet. The principal storage is the Gouin Reservoir at the headwaters where 280,000,000,000 cubic feet of capacity is available.

The storage reservoirs, other than Gouin, are filled each year during the flood periods and completely emptied during the months of low or regulated flow. During the spring flood period of an average year the volume of water impounded at the Gouin Reservoir is increased by 80,000,000,000 cubic feet. The normal reserve of 200,000,000,000 cubic feet at Gouin is used to maintain the river flow at required values during years of

Figure 5. Portion of current-meter chart, La Gabelle power house
Test of unit 2



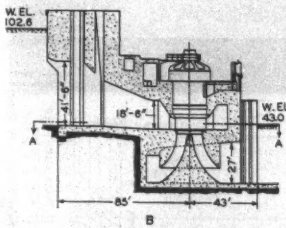


Figure 6. La Gabelle power-house unit, 32,000 horsepower
A. Section A–A
B. Section through unit

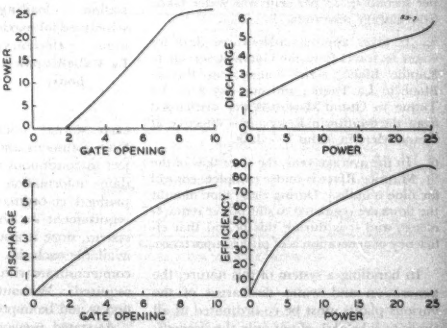


Figure 7. Test result curves
Unit 5—60-foot head

Table II. Comparison of Weekly Operating Efficiencies—Combined Generating Stations on St. Maurice River

Week Ending	March 5, 1944		January 24, 1943	
	Kilowatt-Hours	Per Cent	Kilowatt-Hours	Per Cent
Generation possible with water used at maximum head and efficiency	100,278,300	100.00	113,363,000	100.00
Loss due to reduced head	633,900	0.63	1,494,600	1.32
Loss due to improper loading of units	1,041,800	1.04	3,537,400	3.12
Total loss	1,675,700	1.67	5,032,000	4.44
Actual generation	98,602,600	98.33	108,331,000	95.56

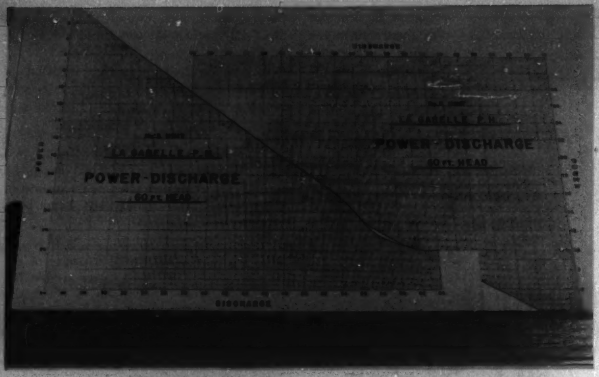


Figure 8. Power–discharge templates

La Gabelle power house—60 feet head
Left—unit 3; right—unit 5

"below-normal" run-off and is replenished in years "above-normal" run off.

The importance of these storage capacities can be seen from the fact that out of an average river flow of 22,500 cubic feet per second at Grand'Mere during the past December, January, and February, 16,500 cubic feet per second or 73 per cent was water taken from storage reservoirs.

5. It takes approximately three days for water to travel from the Gouin Reservoir to Rapide Blanc, eight hours from Rapide Blanc to La Tuque, and one day from La Tuque to Grand'Mere. Water discharged from the Mattawin Reservoir is effective at Grand'Mere in about 1½ days.

6. In the average year, the river flow of the St. Maurice River is under complete control for nine months. During these nine months the flows are regulated to suit power requirements, and it is during this period that efficiency of generation is of prime importance.

In handling a system of this nature, the generation and water discharges of the various plants must be co-ordinated at all times to take care of not only the immediate needs, but also the anticipated future requirements of the system as a whole. Forecasts must be maintained, covering the expected daily conditions for a period of at least seven days in advance. From these, the proper distribution of the daily generation and the discharge schedule for each storage reservoir are determined. Such estimates and calculations are subject to continuous revision as more up-to-date information is available. This planned co-ordination is a fundamental requirement for the operation of such a system, since it assures that the river flow available each day at each station will be commensurate with the average generation required. Without this, efficient operation would be impossible.

As stated previously, reduction in efficiency of generation can result from operation of units at less than maximum head and from the improper loading of units.

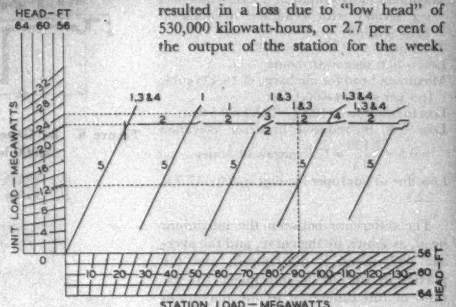


Figure 9. Practical station loading scheduled for maximum efficiency, La Gabelle power house

LOSSES DUE TO LOW HEAD

On such a system, while it is not practicable to eliminate all losses due to "low head," they can be kept to a minimum by careful operation. The control of this item is of particular importance at stations where appreciable forebay pondage exists, and has to be employed in the normal cycle of operation. At the Grand-'Mere Station; for example, it is necessary to draw down the forebay during the weekdays so that the water may be stored, instead of spilled, over the light-load period of the weekend when only a portion of the total water inflow is required for discharge through the station for power generation purposes.

Figure 13 shows how the operation actually is controlled in order to obtain the required result with the minimum of losses. If the river flow had been held constant throughout the week, the variation in the forebay elevation would have been as indicated by the dotted line and would have resulted in a loss due to "low head" of 530,000 kilowatt-hours, or 2.7 per cent of the output of the station for the week.

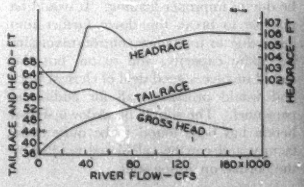


Figure 10. Variation of forebay, tailrace, and head, with flow, La Gabelle power house

By manipulation of the discharge from storage reservoirs, however, the same average flow was obtained but with higher values for the first half of the week and lower for the second half, and with an actual drawdown as shown by the solid line. This resulted in the losses being reduced to just half of what they would otherwise have been.

Under most conditions, the losses due to "low head" at the average station can be held to about three fourths of one per cent.

LOSSES FROM IMPROPER LOADING

The losses due to "improper loading" of units are usually potentially greater than

Table III. Comparison of Weekly Operating Efficiencies—La Gabelle Generating Station

	Week Ending March 5, 1944		January 24, 1943	
	Kilowatt-Hours	Per Cent	Kilowatt-Hours	Per Cent
Generation possible with water used at maximum head and efficiency	14,394,300	100.00	16,620,000	100.00
Loss due to reduced head	32,500	0.22	353,700	2.13
Loss due to improper loading of units	161,800	1.12	1,106,300	6.65
Total loss	194,300	1.34	1,460,000	8.78
Actual generation	14,200,000	98.66	15,160,000	91.22

losses due to "low head" and are more difficult to control.

The maximum possible efficiency of the average generating unit on the St. Maurice River system, as determined by test, is 88 per cent and can be obtained when the unit is operated at 86 per cent of its maximum capacity. If the unit is operated at maximum capacity, or if it is operated at 50 per cent of maximum capacity, the efficiency will drop 8 per cent.

In order to minimize the losses due to "improper loading of units," the general procedure employed in actual practice is to maintain a distribution of the total generation so that all stations, with one exception, will have an assigned output which can be obtained by operating a definite number of generating units with each unit at its point of maximum efficiency. The one exception is the station which is delegated to "frequency control." This station must supply the remainder of the required generation and vary its output to follow the continual changes in total requirements.

At the frequency-controlling station, the generation tends to swing above and below the value corresponding to maximum efficiency, and losses result. If at any time the station becomes loaded to capacity, or if too much spare capacity becomes available, the total generation must be redistributed among the stations concerned.

At stations where all generating units have similar characteristics, the general rule for frequency control, as previously mentioned, is to operate the smallest number of units which will carry the load and to divide the load equally between them. At stations with units which are not similar, or when the units have unusual characteristics, the ideal loading schedule for maximum efficiency may be so complicated that it cannot be followed in actual practice, and some compromise must be made.

When a station is not on frequency control, the problem is to maintain a generation corresponding to a point of maximum efficiency. From a practical point of view, therefore, the essential information required by station operators is with reference to the maximum efficiency point of each individual unit. Knowledge of efficiencies which will be obtained over the whole capacity range of each unit is of secondary importance in most cases, as far as the station operator is concerned.

Where fixed-blade runners are employed, the point of maximum efficiency corresponds to a definite opening of the turbine vanes and should be expressed in this manner as a matter of convenience. The actual output which can be obtained at this efficiency, of course, will vary with the hydraulic head which is available. As a further convenience, it is desirable that remote indication of turbine gate openings be provided in the station control room so that the operator can determine at a glance whether or not each unit is operating at maximum efficiency without having to refer to complicated curves and tabulations.

Under certain conditions considerable saving in losses may be effected by the use of generating units as synchronous condensers. This is the case when the number of units to be kept on the line, in order to maintain satisfactory voltage levels, is in excess of the minimum number required for power generation.

This type of operation introduces no difficulties where the turbine runner is set above the normal tailrace elevation and is common practice on the "Shawinigan" system. When used as a synchronous condenser, the unit operates on the bus with the turbine vanes closed and with the draft tube vented. The venting of the draft tubes reduces the amount of power required to motor the unit. At Rapide Blanc, for example, a 33,000-kw unit requires approximately 3,500-kw to motor with the draft tube unvented, but only 1,000 kw when the draft tube is vented. These values of motoring power include the generator losses at full current.

At the La Gabelle generating station fixed-blade propeller-type runners are employed, and the runners are located below normal tailrace levels. In this particular case, when a spare unit is to be available for any appreciable length of time, the practice is to uncouple the turbine shaft and operate the generator by itself as a synchronous condenser. If this type of unit is operated as a condenser with its runner in water, the motoring power required is 21,000 kw or about 80 per cent of its capacity, which explains the practice of disconnecting the runner.

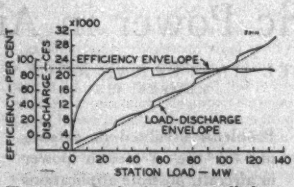


Figure 11. Station load versus discharge and efficiency, La Gabelle power house, 60 feet head

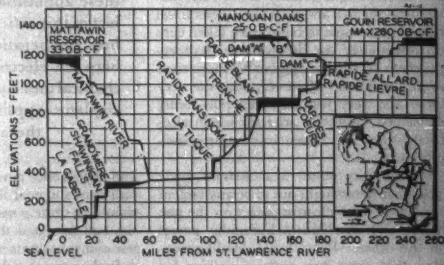


Figure 12. Diagrammatic profile of the St. Maurice River

MAGNITUDE OF LOSSES IN ACTUAL PRACTICE

The total losses in generation on a system of this nature, of course, will depend to some extent on the general load conditions which exist. If the system has to be operated close to its maximum capacity, then efficiencies must be expected which will be lower than those possible under more favorable conditions.

This can be shown by comparing the actual results obtained on the Shawinigan system during the last two winter periods.

By the winter of 1942–43 the power requirements of the war industries were almost at a peak, and, while increased generating capacity gradually was being made available, particularly in the Saguenay River area, the power situation was temporarily critical. In order that the maximum war effort could be maintained during this period, the use of the hydraulic reserves of the Shawinigan Water and Power Company was essential. To maintain the high values of total output, a reduction in efficiency of generation had to be accepted.

In the winter of 1943–44, while power demands were heavy, it was unnecessary to force the output of the generating station to such an extent, and more normal operating efficiencies could be maintained.

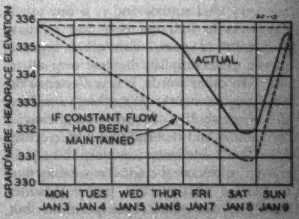


Figure 13. Weekly drawdown of Grand'-Mère headrace

Actual loss due to reduced head . . . . 1.32 per cent or 260,000 kilowatt-hours
With constant inflow loss would have been . . . . . 2.70 per cent or 530,000 kilowatt-hours
Difference . . . . . 1.38 per cent or 270,000 kilowatt-hours

Table II shows a comparison between the weekly operating efficiencies during these two periods.

Table III gives a comparison between the efficiencies at the La Gabelle Station in the same two periods. The difference in efficiency is more noticeable here than in the case of the combined stations.

It must be kept in mind that reductions in generating efficiencies do not necessarily indicate poor operation. For example, if an appreciable increase in the uncontrollable flow of the river is anticipated, as the result of rain, the policy is to increase the generated output at certain stations and draw on the local pondages. Under these conditions, losses due to "low head," or even "improper loading," may be shown for a period, but these will be more than compensated for by the fact that water, which otherwise would be spilled over the dams, will be stored for future use.

There are obviously many factors, other than the efficiency of generation of individual stations, which must be considered if a true picture of over-all conditions is to be obtained. Nevertheless, experience in operating this particular hydroelectric system, where a change of one tenth of one per cent in efficiency of generation represents 5,000,000 kilowatt-hours per year, has indicated that the careful testing of each unit and the setting up of an accounting system as described herein will give adequate returns.

Electric Power in Aircraft

MABEL MACFERRAN ROCKWELL
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Problems involved in extending the use of electric power in aircraft, possible applications of electricity in various types of airplanes, and the development work and equipment needed for these applications form the subject of this article. Not rivalry, but co-operation should exist between electric power and mechanical and hydraulic power in airplane applications, declares the author.

AT THE PRESENT time there is a very fine opportunity for the application of real engineering skill in the extension of the use of electric power in airplanes. Until very recent years airplanes in general have been relatively small and uncomplicated. Control operations could be accomplished readily by direct mechanical means, and such simple electrical functions as came to hand were taken care of adequately by low-voltage battery-magneto systems analogous to those used in automobiles. However, with the very large and very fast airplanes now being developed, problems arise for which electricity presents many interesting possibilities.

At the very outset it should be made clear that there ought not to be any violent rivalry between electric power on the one hand, and mechanical-hydraulic power on the other. Instead, we should recognize that there are many functions for which hydraulic and mechanical power are very well suited, and it is our job as engineers to find the best way to make electricity *co-operate* with other types of power to accomplish the best over-all result. In other words, it is a matter of developing teamwork. We as engineers have the responsibility of soberly balancing all the factors and determining where on the team each element functions best. Of course, as electrical engineers we may tend to believe that electric power is suited ideally to the quarterback position; but, on the other hand, we cannot afford to forget that hydraulic power has a lot of beef and speed and hence cannot be overlooked for the fullback job. In some cases, maybe electricity should call the signals, and hydraulic power should carry the ball over the goal line. However, it also should be quite possible to hand electricity the ball now and then and let it make a few end runs on its own.

In the present article the following topics will be discussed:

1. Possible applications of electric power in various kinds of airplanes.
2. Problems involved in such applications.
3. Development work and equipment needed for successful solution of these problems.
4. Engineering comparison of electric with other kinds of power in the various applications.

POSSIBLE APPLICATIONS IN VARIOUS TYPES OF AIRPLANES

The most significant types of airplane for present and future development are the large long-range transport, the superspeed military aircraft, and the small utility plane for local service and commuting. From the electrical standpoint the large long-range transport offers the most interesting possibilities and will be discussed first.

In these large airplanes now being developed certain uses of electricity are taken for granted. There is illumination, heating, cooking, air conditioning, small devices and gadgets of various sorts, and drives for water and oil pumps.

Another well-established electrical application lies in the essential field of radio communication, now augmented by the convenient interphone system within the airplane.

The next group of applications has to do with *operating* the airplane. Starting the engines is one very important job that electricity is called upon to do; while adjusting the pitch of the propeller blades for maximum efficiency at all times is another. Raising and lowering the landing gear is a vital function which can be well performed by electricity, but unfortunately some "false starts" in the early days more or less retarded confidence in the electric gear and left most designers favoring hydraulic operation for the time being. However, there is now a definite trend toward use of electrically operated landing gear.

A field in which electricity is just dabbling its toes, so to speak, is that of *control* of the airplane. So far, this has been a field pretty well monopolized by mechanical and hydraulic devices. However, propeller pitch controls are electrical, and much interest is being shown in remote-positioning devices for engine controls and secondary flight controls such as tabs and flaps. The greatest challenge is offered by the primary flight controls (rudder, elevators, ailerons) where mechanical and hydraulic operation are still strongly entrenched.

Finally, there is a large field for miscellaneous ingenious electrical applications such as deicing of wings, defrosting of windshields, safety interlocks, and all sorts of horns, sirens, and warning devices.

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Coming now to the field of military airplanes, not much can be said on this subject at present except to point out that many of the electrical applications already noted are obviously needed also in this type of airplane. A superspeed highly maneuverable airplane obviously requires hair-trigger control of great precision. Since it is well known that electricity provides excellent means for obtaining such control, whether it be in a steel mill or a watch factory, it stands to reason that here is an excellent field for electrical applications if only we can develop enough ingenuity on the design end. Furthermore, the possibility of using a network system for transmitting electric energy affords considerable improvement in reliability, as against the hazards of enemy bullets.

In the small postwar utility airplane, applications will not be so spectacular as those already described, but the possibilities are none the less interesting. Many of the ideas developed for the large airplanes doubtless will find application in the smaller ones. Especially there would seem to be a good field for electricity in windshield defrosting, communications, passenger-comfort features, and remote control of various operating functions.

PROBLEMS INVOLVED IN THE SUGGESTED APPLICATIONS

Some of the applications are relatively simple from the electrical standpoint. So far as lighting, heating, cooking, and miscellaneous devices are concerned, the chief requirements are adequate generating and distribution capacity, proper voltage maintenance, proper protection, and adequate reliability for the *essential* portions of the load such as navigation and cockpit lights and radio. These are all problems of "system engineering" and sound rather routine from the standpoint of ordinary commercial power engineering; but when thought of from the standpoint of aircraft applications, the achievement of these objectives is by no means as simple as it sounds. For example, we have as yet no satisfactory means of paralleling a-c alternators on the variable-speed aircraft engines; no lightweight aircraft-type induction relays; no satisfactory sources of standby power other than a battery, which is not of much help if an a-c system is used. Hence, the subject of correct system design even for the elementary applications already listed is not a matter to be dismissed lightly, and deserves more attention than it has received. More will be said on this subject in a later section.

We now proceed to a group of possible applications where there is plenty of room for ingenuity in developing the actual devices themselves. This would include all sorts of defrosting and deicing methods, warning signals, safety devices, and remote-positioning controls for engine, propeller, and so forth. The use of the Selsyn principle for such remote-control devices is now being studied, but apparently nothing much as yet has been done in regard to applying supervisory control with telephone-type relays. The latter is a field which presents most interesting untouched possibilities.

The next group of problems has to do with aircraft motors and involves quite a field for competent electrical design engineering. To begin with, there are the relatively large motors (large, that is, compared to the size of the aircraft generators) used for starters, blowers, pumps, and electric screw-jack actuators. Here very careful thought should be given to the question of whether specially designed windings to limit starting inrush should be utilized, to avoid undue "flicker" on the rest of the system. In the case of very large motors starting under heavy load, such as starters for the large airplane engines of the future, the special winding may be necessary in order to get the motor to start at all. The seriousness of this problem may be minimized by proper segregation of busses to isolate large motors from fluorescent lights and sensitive instruments; or by provision of a relatively large and stable power source as by the use of high-speed excitation on the generators or by paralleling generators. Here again, the importance of studying the *system* aspects of the problem is shown clearly. Especially is this true in the case of the engine-starter problem, which may prove acute.

At the other extreme the fractional-horsepower motors offer a field which has scarcely been touched—at least for a-c systems. A small light rugged motor with self-contained protection will fill a wide diversity of needs.

The last group of applications to be considered is the newest and most difficult—namely, that of airplane *controls*. In this field mechanical and hydraulic methods have been firmly entrenched, and electrical methods are only beginning to enter. As an example, the landing gear represents a vital operating portion of the airplane. A few early attempts at electrical operation did not arouse a great deal of enthusiasm, and hydraulic operation has been greatly in favor. However, a trend toward electrical operation has again developed recently and should probably be more widely accepted this time, since the use of motor-driven ball-nut screw actuators has made available a very efficient unit.

Developments are also under way in electrical operation of what may be called the "secondary" flight controls—tabs, flaps, and so forth. The need here is for a rugged fast-acting actuator, either electric or electrohydraulic.

When it comes to the main flight controls, by which is meant the rudder, elevators and ailerons, mechanical and hydraulic methods are very firmly entrenched—perhaps because they "got there fustest with the mostest," as the general said in explaining a military victory. The main flight controls in large airplanes involve two important requirements—there must be multiplication of the pilot's power and *range of motion*, and there must be "feel-back"—that is, the pilot insists on feeling the *reaction* of the surfaces to the force he exerts on the control stick and rudder pedals. Perhaps some day we shall train a new generation of pilots who are willing to fly an airplane by pushing buttons; but right now such a system cannot be sold. The power multiplication is easy for electricity to achieve; but, the "feel-back" is not.

To approach the problem of introducing electric power into the main airplane control system will require engineering skill of the highest order, because it will be necessary to begin with a thorough understanding of the load characteristics of the control surfaces, based on aerodynamic studies. It will then be necessary to determine how electric power can be made to accomplish the desired results and to integrate the electrical with the mechanical control features. It is quite possible that best results will be obtained by a combination of electric and hydraulic power, since hydraulic actuators are notably light in weight for a given thrust.

There is already a decided trend toward electric transmission of power to each actuator unit, the motor and pump being mounted close to or integrally with the hydraulic cylinder. Such a plan, compared with one in which pumps are located on the main airplane engines and hydraulic fluid is transmitted at high pressure throughout the airplane, can be shown to save considerable weight by the elimination of piping and excess hydraulic fluid. In a large airplane, an adequate electric distribution system is provided throughout the airplane for other electrical applications anyway, and the incremental weight introduced into such a system by "heavying up" for the control loads is not very great. In addition, with such a scheme of electric transmission to localized actuator units, a high degree of reliability is offered, since alternate busses, emergency throw-overs, or networks can be provided so that in the event of failure of one or two engines the essential electric system remains energized and all electric-driven actuators function as before. This is in contrast with the central hydraulic system, wherein if one or more engines fail the pumps mounted thereon are out of service, so that duplicate capacity (and weight) has to be provided in the other engine-driven pumps. Elimination of service and maintenance difficulties from leaks and freedom from troubles arising from low-temperature operation are additional advantages of the electric transmission system.

DEVELOPMENT WORK AND EQUIPMENT NEEDED

Analyzing the various discussed problems, it is found that those most needed are:

A. Electrohydraulic Actuating Units. These should be rugged, light in weight, and self-

contained. Ideally, two or three wires should go in one end, and a variable thrust should come out the other. There should be an adequate range of sizes and speeds of operation.

B. Variable-Speed Control for Actuating Units. To eliminate the necessity for hydraulic valves, it would be most helpful if a clever and rugged control system could be developed which would operate the electrical end of the electrohydraulic actuators at variable speeds and torques matching the aerodynamic requirements.

C. All-Electric Actuating Units. Same requirements as for *A*. Essential to have variable speed and torque control as in *B*.

D. Ingenious Remote-Control and Remote-Positioning Units. Using Selsyn or supervisory principles.

E. Well-Designed Large Motors. For high torque, low inrush.

F. Well-Designed Simple Fractional-Horsepower Motors.

G. Overcoming of Commutation Problems at High Altitude. The use of 110/220-volt d-c equipment offers many advantages if commutating problems under low-pressure conditions can be solved. Considerable progress has been reported in this field.

H. Improved Protective Devices for Aircraft Circuits. Lightweight induction and balanced relays, switches, and trip devices.

I. A Satisfactory Constant-Speed Drive for A-C Generators. Mechanical, hydraulic, or by means of separate turbines driven by exhaust gases.

J. Satisfactory Means of Paralleling A-C Generators. Depends on controllability of the constant-speed drive mentioned in *I*.

K. A Good Development Program on Auxiliary Power. How shall the radio be operated with all engines dead (emergency conditions)? How shall the first engine be started if the airplane has landed elsewhere than on a regular airfield with its local power supply for starters? Shall batteries be used? An auxiliary engine? What about size, weight, and cost?

L. A Careful Study of A-C Versus D-C Systems. There is great need for a careful evaluation of the merits of alternating versus direct current for large airplanes, based on a *well-engineered* system in each case. The a-c system offers the use of simple rugged induction motors and elimination of commutation problems; the d-c system offers flexible performance for control operations, ease of providing standby through batteries, and elimination of the need for a constant-speed generator drive. Weight considerations should be about equal for 110/220-volt direct current as against 120/208-volt alternating current.

M. Development of an All-Electric System of Flight Control. This is a distinctly "long-range" problem and would involve development of means for providing "feel-back" electrically.

N. Adequate "System-Engineering" Studies. A mental attitude should be developed whereby airplane electric systems are viewed *as a whole* rather than piecemeal. Analytical or even calculating-board studies should be made on airplane system problems, just as on commercial system problems. Subjects for such analyses are protection, network distribution, parallel operation, maximum load limit, voltage regulation, and behavior during transient starting conditions.

COMPARISON OF ELECTRIC WITH OTHER POWER SOURCES

It is necessary to admit that hydraulic power does certain things superlatively well, and that direct mechanical contrivances (pulleys and levers) give a very satisfactory sense of solidity and ruggedness. On the other hand, electric power has great flexibility, especially from the control standpoint. The most inviting field of application for electric power, at present, lies in the control and transmission of energy.

To substitute electric for hydraulic and mechanical power in large operating units will involve much careful study and ingenious development, and will only be warranted if advantages of weight or reliability can be shown to result. Before a correct comparison can be made, it probably will be necessary to engineer an all-electric airplane and compare it on an over-all basis with an all-hydraulic and mechanical airplane. It is hoped that in the postwar period, time will be found to approach this problem with adequate care and skill.

A Shipyard Public-Address System

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THE Richmond yard 2 of the Permanente Metal Corporation has been using a high-power public-address system for 24 months. With more than 2,000 paging calls each day, it has been highly successful. The calls are limited to those directly affecting production. Trucks, cranes, inspectors, and foremen are called to places in need of them. Much time is saved by reducing the time a crew of men has to wait for its work to pass inspection or to receive new orders. For example, the breakdown of a whirley crane means that all riggers, shipfitters, pipefitters, shipwrights, electricians, and welders must wait for needed material until the crane is repaired. As it requires specially trained electricians and mechanics, who may be scattered throughout the yard, to repair a breakdown, the public-address system is vitally important in locating these men.

This system differs from the average public-address system in that it covers a huge plant employing from 20,000 to 30,000 workers in an industry in which the noise level is extremely high. The system includes high-level paging and music channels. Although music is broadcast six times a day to entertain the workers and to aid in clearing the gates at the close of each shift, paging is the major function of this system.

The high-power public-address system described in this article covers a shipyard employing from 20,000 to 30,000 workers and includes plant protection, paging, launching, and music. Problems encountered in setting up and administering the system are analyzed.

There are five operating stations, and a system of importance rating is used, the entire operation being fully automatic. Each operating station is assigned a rating whereby it can take control of desired parts of the yard above other stations with lower ratings.

The ratings are:

1. Plant protection.
2. General paging.
3. Launching.
4. Local paging.
5. Music.

Numbers 2 and 3 are interchangeable, as some launching and special-events programs are more important than others.

The system consists of individual booster amplifiers, totaling several thousand watts.

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It is operated remotely through an automatic-relay board and is operated during blackouts.

The yard is divided into more than 40 areas, each of which is served by one or more amplifiers and the necessary loud-speakers. All stations have switches and indicator lights for each area in which the station is interested. Simultaneous broadcasting in different areas from various stations is an integral part of this system.

Two initial problems are encountered in designing and installing a system of this type. The first, after the area to be covered has been decided upon, is the amount of power required. The second is the number and location of loud-speakers required to distribute this power. The first depends upon the extent and noisiness of the area.

Noise levels well above 100 decibels have been found in restricted locations in the yard. It is not practical to cause the audio output to approach this noise level, as this would mean the spreading of this level to most of the area covered by the loud-speakers with the attendant bad effect on the ears and nerves of the workers in that area. Therefore, a compromise volume is used which has proved effective.

The number of loud-speakers used depends upon the amount of power needed and upon the nature of the area. The presence of many buildings or obstructions, high prevailing winds, and large areas with little noise (the last because of blasting caused by high volume concentrated in a beam), all require a large number of loud-speakers, possibly with very little power in each.

In the shipyard traveling cranes limit the setting of poles so that there are few places where loud-speakers can be mounted. Therefore, it has been necessary to locate loud-speakers at the head of each shipway on existing lighting poles (Figure 1, part *A*). This means that an area 300 feet long must be covered with each loud-speaker group. This area is the noisiest in the yard. However, the situation is not so black as that statement would suggest, since the highest noise level is closest to the head of the way, as shown graphically in Figure 1, curve *B*. The voice distribution alone is shown in Figure 1, curve *C*, which is also loudest near the head of the way. Therefore, the loud-speakers at the head of the ways can be driven at a high-power level, and a distribution curve can be obtained which, relative to the noise level, is flat enough to insure good results over the entire area (Figure 1, curve *C*). Were it not for this type of noise distribution, this nearly flat curve would not be possible without extremely high poles, or blasting would occur. This does not apply to quiet periods when a different volume level is used, or to areas between the ways.

With the location of the loud-speakers comes the problem of setting the direction of these speakers. This is extremely important, as the usefulness of a system can be destroyed by an uncontrolled echo. An "echo" also can be noticed by one who hears two loud-speakers, one of which is located at a greater distance from the listener than the other. Figure 2 shows a trouble area adjacent to a building, caused by an echo from the walls. This echo cannot be heard within 55 feet of the wall, as the ear fails to detect the time lag. However, beyond 55 feet, the echo is distinguishable, but ceases to be troublesome about 125 feet from the wall, because of the relative difference in the level of incident and reflected wave.

The solution, then, is so to direct the loud-speakers that the concentrated power in the beam of the loud-speaker does not strike the wall directly, but at some intermediate point between the building and the way. The loud-speaker must not be "angled" out too much, as it might then cause an echo in areas covered by other loud-speakers.

Figure 1, curve *D* shows the relative distribution of the yard noise level during change of shift. As can be seen, it differs

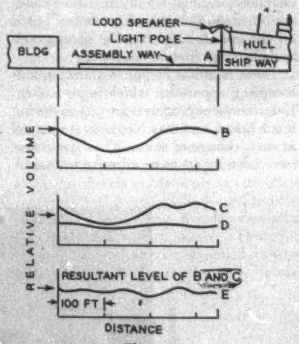

Figure 1

materially from the noise level during working hours (Figure 1, curve *B*). The principle illustrated in Figure 1, curve *E* hardly applies. Therefore, the level used for music is about ten decibels lower than that used for paging.

Although the amplifying equipment in the yard is of the high-fidelity type, that is, essentially flat from 50 to 10,000 cycles per second, the projection horns used in the yard have a frequency response of 165 to 5,000 cycles per second.

Frequencies higher than 5,000 cycles per second are of little use in the yard because of extraneous yard noises, wind, and the like. Bass frequencies below 165 cycles per second are eliminated because much of the power of the human voice is in this region and does not contribute to the intelligibility of speech.

The paging amplifiers are so designed that they do not reproduce needless bass frequencies to prevent overloading of the loud-speaker driver units.

When the paging was first started an amplifier was used that compressed the signal three decibels on peaks, thus doubling the average power of the system by allowing the amplifiers to be turned up three decibels without overloading.

However, the paging announcer forgot to watch the volume-indicator instrument and overrode the limit set for him. The power increase was tremendous. Resi-

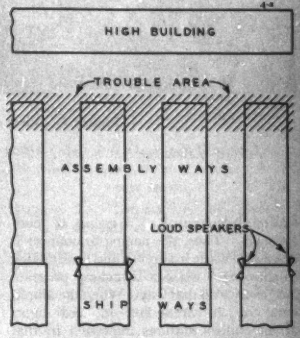

Figure 2. Trouble area adjacent to building caused by an echo from walls

dents of Richmond who lived as much as five miles distant called up at night to tell us to please turn off that "— thing, so we can get some sleep." The prevailing winds there blow toward Richmond.

The human voice, in pronouncing words, creates sounds which have peaks many times the average loudness. The volume must be loud enough so that the softest word or syllable can be heard distinctly over all the area covered. Therefore, the peaks are louder than necessary and serve only to cause echoes and disturb sleepers.

A peak-limiting system has been built into the preamplifiers which comes into operation suddenly at a given volume level and actually restricts the output, within close limits, to a predetermined level. It is no longer necessary to worry about talking not too loudly, not too softly, for one can do nothing about it. The output volume is maintained constant, regardless of the strength of the speaker's voice.

A unique system of indicating lights is used on the switchboards. Each loud-speaker group is controlled by a three-position lever switch, above which are two pilot lights, one green and the other red. The green lights indicate which

Figure 3. View of main check gate

Location of loud-speaker is in circle. Officer with microphone is in upper right-hand corner

station has control of a group of loud-speakers. Thus, the paging announcer is not apt to waste his breath and time talking to shipway 5 when a launching program has priority on that way. When the amplifiers for an area are on, red lights at all control stations interested in that area are lit. If either the plate or the filament fuse should blow, the power fail for any reason, or the output tubes fail, those lights would go out. This provision facilitates maintenance and paid special dividends when the power company had trouble and the line voltage rose more than 50 per cent. No damage was done to amplifiers as fuses, automatic controls, and so on, were sufficient protection, but this occurred during a program and the light system enabled the operators to know at once which sets could be put back on the line when the voltage was normal again.

The three-position remote-control switches allow quick selection of mixed areas. The up position is "on," the middle is "master circuit," the lower is "off." No power is on unless the grip-to-talk "mike" handle or equivalent switch is closed. Switches are normally in the "master" position. If one area only is wanted, that switch is turned up; if all are wanted, the master is turned up; if all but one are wanted, that one is turned down. Several area masters are also provided.

All switching is done at low level (zero decibels), using d-c relays. Automatic action is obtained through the use of electrical interlocks.

The music control room has two control boards, one for the inside studio, the mixer of which has three microphone channels, three phonograph channels, and two radio channels (one high-fidelity broadcast band; the other short-wave). The control board for the outside stage has one phonograph and three microphone channels.

There is also a complete transcription-recording apparatus, which is used often. Entertainment programs are put on during lunch hours, and march records are played at each change of shift. These programs have been found to be effective in morale building. The use of the public-address system during change of shifts has been found to clear the gates about 53 per cent sooner than would otherwise be the case. The yard police department reports that, since the public-address system has been in use, 10,000 workers clear the check gates in nine minutes instead of 17 minutes, and that a substantial reduction in the number of accidents has been effected. In Figure 3 a circle shows the location of the loud-speakers covering this area.

Besides the microphone having ultimate control over the yard, the plant-protection setup in this yard includes local microphones and intercommunication devices, a high tower with directional loud-speaking equipment for directing automobile traffic in the parking lot, and a receiver and transmitter which are tuned to the frequency of the Richmond police radio.

There is portable equipment to be used during launchings, including amplifiers for local loud-speakers on the launching platform. A channel automatically connects the launching equipment to the rest of the yard and to the recording apparatus. The launching apparatus is set up in a few moments, as everything is made to plug into receptacles already mounted. Besides the loud-speakers in the yard, there are loud-speakers located on the launching platform and also one at the trigger. In this way the launching crew knows how the ceremonies are progressing, so that they may have everything correctly timed. Important ceremonies and speeches are recorded. This equipment can be operated from any shipway or dock in the yard.

The yard is crisscrossed with a network of interoffice-communication loud-speaking units, three types of which have been developed to meet particular problems associated with this type of plant. High noise level, bad electrical interference, and so forth, have all produced problems in regard to electrical communications.

It is extremely difficult to evaluate such intangibles as future time and materials saved through the use of this system, as well as immediate man-hours saved by lessening the time crews must wait for leaders, materials, repairs, and so on.

A conservative estimate of messenger time saved during the past 24 months amounts to more than 404,912 man-hours, and an estimated saving in production of 907,056 man-hours to date can be accredited to the public-address system.

Figure 4. Studio control panel and remote switches

Application of Statistics to Dielectrics

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The application of statistics to insulations poses three important engineering problems which according to these authors have not been given the consideration they deserve: (1) establishing a specification for a material which adequately defines its characteristics; (2) formulating a method of evaluating the material to assure both supplier and user that the material meets the specifications; and (3) translating the material specifications into design practice. In this article solutions to these problems are outlined.

THE INSULATION FIELD is well supplied with a very large variety of materials. When these materials are used in large quantities, such as slot insulation in a motor, the uniformity of the material over a long period of time is essential. This uniformity is assured only by the adequacy of the specification and the faithfulness of the manufacture, the inspection, and the test.

Let us consider the properties of a certain kind of paper used as an electrical insulation. In the past the specifications usually have called for some average dielectric strength, sometimes with an allowable percentage variation. This is a very weak specification, because it does not clarify the meaning of an allowable variation. If this is interpreted as a permissible variation in the average, then we must expect individual dielectric tests to deviate considerably more than this amount. It is well known that, if dielectric tests are made on a large number of samples, failures will occur over a range of voltages. Figure 1A is a bar graph of the dielectric strength representing 150 tests on a paper 15 mils thick. This graph is obtained by plotting as ordinates the number of test failures that occur in ten-volt class intervals expressed in volts per mil. This shows a considerable spread in failure voltage. Fortunately, there are numerical methods of expressing this spread in terms of units of the abscissa, namely: standard deviation and range.

Determining the range involves a single computation, that is, subtracting the minimum readings from the maximum readings found in the sample involved. On the other hand, the standard deviation is calculated by squaring all of the individual deviations, adding the squares, dividing by the total number of deviations, and taking the square root of the quotient. The standard deviation for the data expressed in Figure 1A is 32.2 volts per mil, whereas the grand average is 542 volts per mil. Physically this means that about 99.7 per cent of all the test data normally would fall within a distance of three standard deviations on each side of the mean, that is from 445 to 638 volts per mil.

A theoretical normal curve can be drawn as in Figure 1B to represent facts shown by the bar graph. The peak of the curve will correspond to the grand average. Its extremities for practical purposes extend to plus and minus three standard deviations from the mean. This normal curve is defined accurately by specifying the mean and the standard deviation. Thus, the average of 542 volts per mil and a standard deviation of 32.2 volts per mil define the dielectric characteristics of the 15-mil paper under some qualifying test conditions. As long as these two values remain the same, the uniformity of the material may be assumed to remain constant.

During the present emergency, the engineer often is required to use substitute materials. It is very difficult to select the proper substitute if only average values for the characteristics are known. However, the type of information supplied by statistical analysis permits the most fundamental comparison of materials of any method available. Suppose, for example, that a second material has a mean dielectric strength of 575 volts per mil and has a standard deviation of 75 volts per mil. Judging from the average values alone, one would be forced to conclude that the material having the higher value would be the better material. The distribution curve for the second material is superimposed in Figure 2 over the curve of the original material in order to show more clearly the effect of the standard deviation. It is very doubtful now if the second material is better than the first. In fact, if both materials were subjected to 475 volts per mil, nine per cent of the second material would fail whereas only 1.8 per cent of the first material would be rejected.

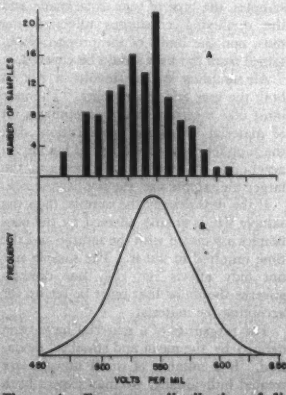

Figure 1. Frequency distribution of dielectric strength of 15-mil paper

A—Bar graph representing tests on 150 samples
B—Theoretical curve representing data in A

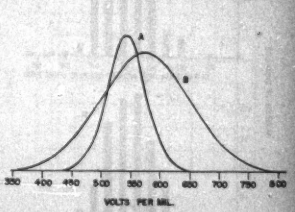

Figure 2. Comparison of dielectric strength of two materials

A—Mean 542 volts per mil. Standard deviation 32.2 volts per mil
B—Mean 575 volts per mil. Standard deviation 75 volts per mil

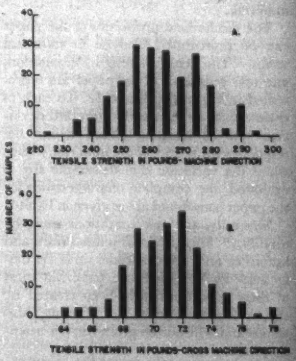

Figure 3. Frequency distribution of tensile strength of 15-mil paper

Essential substance of a conference paper presented at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944.

C. M. Summers and K. E. Ross are both with General Electric Company, Fort Wayne, Ind.

The two materials illustrated are not equivalent. Substitution of the second material would have resulted in a poorer product, or at least one having a greater number of rejections, if an engineering limit of 475 volts per mil had to be met. The value of the statistical specification, therefore, is very real, as a means not only of defining the required quality of the raw

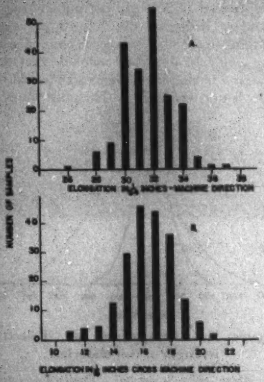

Figure 4. Frequency distribution of elongation of 15-mil paper

material, but also of selecting substitute materials.

The mechanical properties of the paper can be represented likewise in statistical terms. The tensile strength, elongation, and tear resistance of the paper are represented in Figures 3, 4, and 5. To each of these curves a mean and a standard deviation can be assigned which define the respective properties of the material. Thus when the variation due to sample size is excluded, the complete characteristics for the paper considered are as given in Table I.

Naturally, the test conditions must be qualified. Such items as temperature and humidity and test electrodes must be designated for the dielectric tests, but most of these conditions have been treated by the American Society for Testing Materials and will not be given further attention here.

There is another important factor that should be considered in making a specification: that is, to specify the most significant properties. For example, tensile strength and tear resistance are important for a material to be used as a slot insulator for a motor, because the material is subject to these mechanical actions during the manufacturing process. The same mechanical properties would not be important in a layer insulation, but other properties would be specified significant of the results expected of the material.

Table I. Characteristics of the Paper

	Mean	Standard Deviation
Dielectric strength	542.0	32.0
Tensile strength *MD**	263.0	13.0
Tensile strength *CMD**	71.0	2.8
Elongation *MD*	0.5	0.028
Elongation *CMD*	1.02	0.12
Tear resistance *MD*	48.2	2.2
Tear resistance *CMD*	81.9	2.9

* *MD*—Machine direction. *CMD*—Cross machine direction.

EVALUATION OF MATERIAL

After the specification has been established, there must be a common basis upon which both the supplier and user can sample and test the material to determine

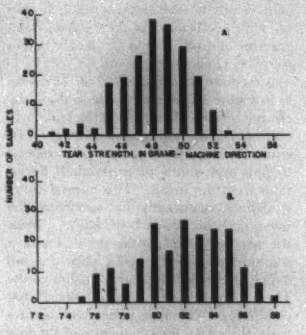

Figure 5. Frequency distribution of tear strength of 15-mil paper

its conformance with the specification. The method of such selecting and testing of the sample may be defined clearly in the specification. The selection of the samples, the type of tests to be made and the qualifying conditions affecting the tests, and the limits of the properties obtained from the tests should be covered.

All sampling systems involve a risk to both the user and the supplier. The user must take a certain risk of accepting a lot of material below the specification, and the supplier must take a risk of having an acceptable lot rejected. In general, the larger the sample size, the smaller the risk.

If the tests destroy the sample, then the sample size is greatly affected by the economics associated with the sample and the time required to test it. The sample size not only affects the risk, but directly governs the limits that must be set up for accepting the material.

The properties of a material have been defined by the mean and standard deviation. If a number of small samples are treated individually, we may expect both the mean and standard deviation to vary within the limits established by the sample size and still be acceptable. Accordingly, the acceptance chart based on a sample size of 25 is shown in Figure 6 for dielectric strength of the paper represented in Figure 1. As long as the mean and standard deviation lie within the limit lines, the sample is acceptable. In similar manner, the limit lines can be set for all other qualities based on a statistical specification.

TRANSITION TO ENGINEERING PRACTICE

Even when the engineer has all of the available data on a material, he seldom can incorporate this information directly into design practice. The engineer must modify the known characteristics by factors of safety, in order to compensate for the many factors that influence a material from its raw state to the finished product. Mechanical treatment, moisture absorption, subjection to high temperatures, and many other factors are encountered in the manufacturing processes which may alter the characteristics of the insulation, so that the original properties defined by the specification are invalidated.

The finished product practically never

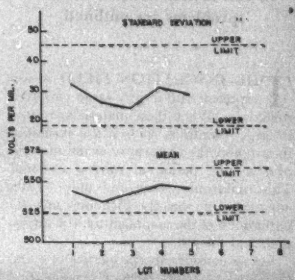

Figure 6. Control limits of standard deviation and mean values of dielectric strength of 15-mil paper based on a sample size of 25 units

operates under the same conditions of time, temperature, and voltage stress as those established by the material specification. Even the thickness of the insulation may be different, and the size and shape of the equivalent electrodes are radically different in the finished product.

The engineer must rely upon past experience to guide him in introducing factors of safety to offset all of these adverse conditions. While many of the factors may defy all types of analysis, some of them can be analyzed statistically in a manner that will provide the engineer with some very valuable data. For example, the effect of time and temperature on the dielectric properties of an insulation is suitable for statistical study.

OPERATING CONDITIONS

It is well known that the dielectric strength of most materials decreases as the voltage stress is applied for longer and longer periods of time. In fact the con-

tinuous dielectric strength of some varnished cloths may be as low as one third of the short-time strength. The general shape of the mean time–dielectric-strength curve appears as curve *B* in Figure 7.

This curve is obtained by applying several values of voltage, less than the instantaneous breakdown strength, and holding each voltage until failure occurs. Naturally, if a large number of samples are used, they will not fail in the same length of time; hence a time–frequency-distribution curve can be obtained for each value of voltage. This is represented by *G* in Figure 7. If the material has a statistical specification, the short-time dielectric-strength–distribution curve similar to Figure 1 will be available and is represented in Figure 7 by *F*. A curve then can be drawn through each extremity of the various distribution curves *A* and *C* and another curve through their means. Then we should never expect to find any failures at any voltage in a time less than that defined by curve *C*. If the equipment must

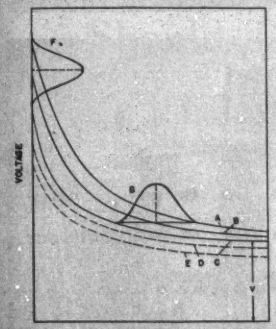

Figure 7. General frequency distribution of time life characteristics of an insulation material

A–B–C—Curves drawn through the mean and extremities of several frequency-distribution curves similar to G and F

D—Design-objective curve

E—Test-objective curve

operate continuously in service, the engineer can establish a value of *V* volts per mil as a maximum value to use in design practice.

The curves shown in Figure 7 apply at only one temperature and humidity. To

Table II

Voltage	Time	Temperature
V_1	x_1	T_1
V_1	x_2	T_2
V_1	x_3	T_3
V_2	x_1	T_1
V_2	x_2	T_2
V_2	x_3	T_1

make the story more complete, therefore, there should be a series of similar curves representing a range of operating temperatures and humidities. Naturally, a lot of time and effort is required to secure the mass of data required. If these curves could be established, however, a design-objective curve (*E* in Figure 7) could be set up on a more fundamental basis than at present. No doubt, there would be other factors, such as mechanical abuse, that would have to be represented in the design-objective curve, and perhaps these could be evaluated in some manner. If not, the engineer still would have to rely on past experience to locate the design-objective curve. However, the more items that can be evaluated accurately, the less

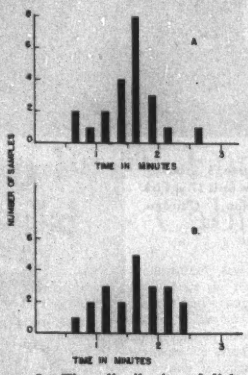

Figure 8. Time distribution of dielectric failure of a molded part

A—Tests at 14,000 volts and 125 degrees centigrade

B—Tests at 18,000 volts and 115 degrees centigrade

becomes the importance of errors in judgment applied to the factors which cannot be analyzed.

TEST OBJECTIVE

In addition to the design-objective curve, a test-objective curve can be recommended, such as *D* in Figure 7. In testing the insulation system, any applied voltage and corresponding time along this curve should produce a failure only in a defective unit. Quite often the question arises regarding the equivalence of a dielectric-test voltage when two time elements are involved. For example, if a ground-test voltage of 1,500 volts is applied to an insulation system for 30 seconds, what equivalent voltage should be applied for one minute? A test-objective curve as in Figure 7 should provide the answer, and this hypothesis is substantiated partially by experience with a molded part, where temperature as well as time had to be considered. This part was originally tested at 125 degrees centigrade at 14,000 volts for 30 seconds. Later it became necessary to reduce the temperature to 115 degrees centigrade. The problem was to determine a test voltage and a time of application which would guarantee the same product quality under the new conditions. A time–distribution curve was taken on a number of samples at 125 degrees centigrade by applying 14,000 volts until failure occurred. The results are shown also in Figure 8A. Then the temperature was reduced to 115 degrees and the voltage raised until a time–distribution curve was obtained similar to the original. It was found that a test voltage of 18,000 volts

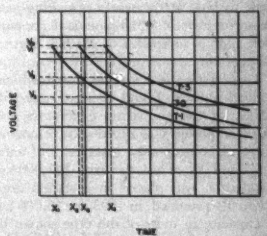

Figure 9. Equivalent test conditions involving voltage, time, and temperature

produced this equivalence as shown in Figure 8B. Furthermore, the time of 30 seconds for the test produced about the same percentage of failures as the original test. The same voltage (14,000 volts) applied for a longer time at the lower temperature would have produced an equivalent test. This equivalence can be shown on the voltage–life curves in Figure 9. Each curve represents mean values of a large number of tests. If the deviation from the mean is of the same order, throughout the conditions represented, then the values given in Table II are essentially equivalent.

CONCLUSIONS

An attempt has been made in the foregoing discussion to point out the value of statistical methods in establishing a specification which adequately describes an insulation material. The control-chart method, based on an agreeable sample size, is suggested for determining whether or not the material adheres to the specification. A virgin field is represented in the transformation of the characteristics of a material into data suitable for design purposes. The statistical method provides a powerful tool for analyzing such properties as the effect of time and temperature on the properties of a material. The proper analysis of any material depends on the measurement of one or more of its characteristics. Thus, the value of the analysis depends on selecting the most significant property to measure. The ultimate aim would be to measure a quantity that would represent the performance of the material in the finished product.

New 147,000-Kw Unit at Fisk Station

OUTSTRIPPING in capacity any other turbogenerator placed in service in the United States since Pearl Harbor, the new 147,000-kw unit 17, shown in Figure 1, at Commonwealth Edison Company's historic Fisk station in Chicago, Ill., is now running under full load and playing an important role in the job of meeting the huge power demands of war-production industries. It embraces what is claimed to be the largest single-shaft turbine in the world operating at a steam pressure of 1,250 pounds per square inch and a temperature of 925 degrees Fahrenheit.

To provide space for the new machine, vertical units 8, 9, and 10 were removed. Room for the two steam generators and four feed pumps was afforded by removing the boilers originally installed for units 6, 7, and 8. Thus the new 147,000-kw installation was placed in a station area originally provided, in 1903, for 15,000 kw of capacity in units of the type shown in Figure 2. Actually it replaces obsolete units representing installed capacity of 36,000 kw as shown in Table I.

Two steam-generating units, each designed to provide 750,000 pounds of steam per hour at 1,325 pounds per square inch and 935 degrees Fahrenheit, are provided. They are of the Babcock and Wilcox high-head type, equipped with continuous-tube drainable superheaters, continuous-tube economizers, tubular air heaters, inter-tube-type attemperators, water-cooled furnace walls, and continuous-slag-tap furnaces.

Fuel fired in this installation is central Illinois coal, which has an ash content of approximately 14 per cent. Electric precipitators, one for each boiler unit, are located in the gas duct between the air heaters and induced draft fans. They collect 90 per cent of the fly ash borne by the gases before they discharge to the stack.

Four 600,000-pounds-per-hour 1,600-pounds-per-square-inch boiler feed pumps are provided for the installation. Three are driven by constant-speed 1,750-horsepower 3,570-rpm motors and one by a 1,540-horsepower 3,340-rpm turbine. Feed pressure is controlled manually from the motor-driven pumps by throttling the pump discharge valves. Control with the turbine-driven pump is attained by regulating its speed. Normally the turbine-driven pump is used as a spare.

Table I. Fisk Station Installations

Unit	Capacity (Kw)	Service Date
Old No. 1	5,000	10- 2-03
Old No. 2	5,000	12-11-03
Old No. 3	5,000	4-21-04
Old No. 4	7,500	10-27-04
No. 5	12,000	9-17-06
No. 6	12,000	10-10-06
No. 7	12,000	11-13-06
No. 8	12,000	1-22-07
No. 9	12,000	7-19-07
No. 10	12,000	9-17-07
Replaced No. 4	12,000	5-21-09
Replaced No. 3	12,000	6-14-09
Replaced No. 2	12,000	9- 3-09
Replaced No. 1	12,000	10-28-09
No. 14	20,000	3-30-14
No. 11	25,000	6-21-14
No. 13	30,000	12-24-19
No. 12	35,000	1-18-20
No. 15	30,000	10- 8-37
No. 17	147,000	12-11-43

Figure 1 (above). New unit 17 at Fisk station, Chicago, Ill.

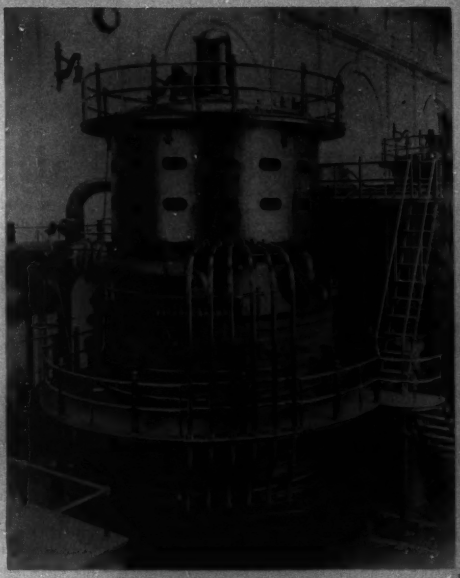

Figure 2. First turbine in Fisk station

"Amazingly large" was the phrase used to describe this pioneer 5,000-kw turbogenerator some 40 years ago when it was placed in operation

The steam path of the 1,800-rpm Allis-Chalmers tandem-compound Curtis-reaction condensing turbine consists of a Curtis stage and 39 reaction stages. Blades in the last row of the double-flow low-pressure turbine have a tip speed of 1,135 feet per second. The throttle steam flow at full load is 1,262,000 pounds per hour, while the condenser flow is 845,300 pounds per hour. The difference of 416,700 pounds per hour is bled for feed water

heating. In all, five bleed points are provided. Final feed water temperature of 455 degrees Fahrenheit is attained.

Because of the large amount of steam required, the turbine is provided with two steam chests, one on either side of the high-pressure cylinder. On each steam chest is mounted a 14-inch throttle valve and three 12-inch admission valves. An equalizing line connects the two steam chests to equalize flow at high loads. The blade-carrying portion of the high-pressure spindle is machined from a solid single forging. A stub end is shrunk, keyed, and bolted at the low-pressure end. The low-pressure spindle consists of a built-up welded assembly of forged-steel disks and two forged-steel shaft ends. This construction, unique in design, is used to insure a sound structure in the size of spindle involved.

The generator is a 147,000-kw 60-cycle 12,600-volt, three-phase air-cooled unit. It is designed for operation at 85 per cent power factor. Because of the machine's large capacity both in kilowatts and amperes, its armature has two electrically independent windings, each of which connects to a separate bus system. The terminals of the two windings are brought out on opposite ends of the armature to relieve congestion of cables under the machines as much as possible.

Because of the large size of the field, its core is built up of a forged steel shaft provided with axial serrated grooves into which teeth are fitted to form the sides of the coil slots and the center of the poles. This construction avoids the extremely large forging that would be required if one-piece construction were used as on smaller machines.

The turbine heat rate at full load is 8,750 Btu per kilowatt-hour gross. The auxiliary power at full load amounts to about 7,000 kw so that with a boiler room efficiency of 87 per cent the over-all net heat rate will be about 11,000 Btu per net kilowatt-hour.

With the addition of unit 17, Fisk—the first all-turbine station in the United States—marks another important milestone in power-generation development. This single machine, with its two steam generators, has more than twice the capacity of the 14 units and 112 boilers originally conceived for the station. When compared with the original units on the basis of floor area occupied the concentration of power is tenfold. Capacity per unit installed has been increased 30 times and performance has been improved 500 per cent.

Should There Be an Engineer in the President's Cabinet?

CREATION of the position of Engineer-Consultant in the President's Cabinet is urged by H. L. Fruend, water-control planning board, Tennessee Valley Authority, Knoxville, Tenn., in an article published in the September 1944 issue of *Civil Engineering* (pages 393–4). His plan is outlined in the following paragraphs, which are quoted from the article.

"The plan . . . is relatively simple. It calls for no great change in established governmental procedures. It recognizes the functions of existing agencies and bureaus. It seeks no definite control of anything. Its services are strictly advisory. It will encounter much opposition from powerful groups having their own schemes. But if adopted it eventually will punch the bottom out of the pork barrel.

"This suggested plan is to enlarge the President's cabinet to include a consulting engineer, whose position would be similar to that of the Attorney General and whose title would be Engineer-Consultant. The powers of the Engineer-Consultant would be solely those of technical adviser to the President. No Federal agencies, bureaus, or services would be assigned to his office or administered under his direction.

"The Engineer-Consultant, however, would have the power at any time to investigate the activities of any agency conducting or supervising engineering operations for the Federal Government and to submit a confidential report of his findings and recommendations to the President, but he would be under no obligation to do so except on presidential request.

"His regular duties would in no way interfere with his work as a consultant, and his primary duty would be to advise the President on the feasibility, need, and economy of all legislation and executive orders making provision for engineering services or involving the installation, operation, or administration of public works, or for conducting other engineering activities. In such capacity, his services as a consultant would be made available to congressional committees, Federal bureaus, and other national agencies when and if requested. As an official member of the Cabinet, the Engineer-Consultant would be appointed by the President and would hold office only at his will and discretion.

"To a large extent the staff would consist of recognized specialists in technical lines, whom the Engineer-Consultant might appoint either temporarily or permanently, and who would not be subject to Civil Service regulations. He would open such regional offices, either permanent or temporary, as might be required to conduct readily the duties of his office, and he would have the power to employ competent private engineering firms or professional engineers to conduct special studies or make a report.

"The Engineer-Consultant would maintain a register of all professional engineering firms and technical engineering experts qualified to practice before his office and registered in the state wherein the work is to be done, or the engineering operations carried on.

"To the maximum extent practicable, the consultant would select from this register an engineering firm or professional engineer of recognized ability and standing to conduct specific investigations or studies—one who, in general, would be cognizant of local needs and requirements. The compensation for this consultation would be in accordance with such uniform schedules of fees or per-diem rates for engineering services as might be adopted by the so-called national Founder Societies for the private practice of engineering.

"Unless otherwise required by law or executive order, the Engineer-Consultant would assign any authorized project involving the design, construction, operation, or maintenance of public works, or the rendering of regular and continuous engineering service, to the proper Federal engineering bureau or agency established for carrying on such work or related effort. The Engineer-Consultant would not carry on or supervise directly either the construction or the operation of any public project.

"The Engineer-Consultant would keep the President advised upon the proper coordination of all Federal engineering services to the extent of avoiding duplication and inefficiency, and he would have the power to effect the temporary transfer of engineering specialists and their staffs from one Federal agency to another in order to conduct related engineering operations of the Government more efficiently.

"However, he would have no power to direct or to interfere with the work of any Federal agency to the extent of impeding its regular operations or lowering its efficiency.

"The Engineer-Consultant would endeavor to maintain the highest degree of efficiency in all Federal engineering services and to co-operate with state and local authorities having a direct interest in any project. To this extent, his preliminary engineering studies and investigations would not be limited by claims of exclusive jurisdiction or regional control which might be held by any other department or body."

VII. Aircraft Electricity

T. B. HOLLIDAY
MEMBER AIEE

World War II has taught designers of aircraft electric equipment many valuable lessons which will be applied to peacetime production to create more powerful, lighter-weight, and more efficient electric apparatus for aircraft and other fields.

WAR is an unprofitable enterprise. However, one of the brighter sides of war is that problems and their solutions which develop from military necessity become commercial advantages. In other words, wars make better things for peace. It is quite likely that the advances in electrical-engineering art which have resulted from aviation electricity will fall into this category.

Practically all of the outstanding progress in aviation electrical engineering is confined to a period of ten years. Shortly after the first World War, electric apparatus began to appear in aircraft. Aside from its application for the ignition system which was discarded in favor of the magneto, the first use was for aircraft lighting. This lighting was rather crude, since it consisted of wing tip and taillights, to mark the position of the airplane, plus cockpit lights, by means of which the instruments could be read. Use of this lighting equipment required a storage battery which was installed as needed for a night flight.

Since aircraft engines were becoming larger, the problem of starting them was becoming more difficult. Therefore, the next logical application was that of an engine starter. This required a larger battery, and, to avoid the problem of frequent replacement of the battery, a generator was installed to keep the latter charged. This simple lighting system and engine starter were the small beginning of a long list of electric apparatus which now appears in the modern airplane.

DEVELOPMENT OF GENERATORS

The development of generators which have been produced by the electrical industry is the most amazing of all and is the foundation for the wide usage of electric equipment. Some of the problems encountered by the engineers who developed generators must be understood in order to appreciate fully their accomplishment. For many years the generator has been restricted to a space on the accessory section of the engine having a maximum diameter of $6^1/_2$ inches. In many engines even this amount of space is not available. Regardless of the amount of power which was required by the electric system, the generator could not exceed this dimension.

The generator, which was standard equipment until as late as 1939, was six inches in diameter, weighed 32 pounds, and produced 750 watts (50 amperes at 15 volts) at a minimum speed of approximately 2,300 rpm. This generator weighed more than it should, because the voltage regulator used with it was the single-vibrating-contact type sometimes described as the Tirrill. In order to obtain satisfactory life of the contacts, field current had to be restricted to 1.5 amperes. The way for lighter generators was opened by the development of other types of voltage regulators. These types might be described as multicontact and carbon-pile types. With these, the field current could reach a maximum value of eight amperes. Use of the higher values of field currents permits working the magnetic sections of the generator to the maximum extent. This step cut the amount of iron to approximately half its former value with a corresponding reduction in the length of copper windings. As a result, it was possible to cut the weight of generators having the same rating practically in half.

The progress in this development is best shown by the downward trend of the specific weight of generators in terms of pounds per kilowatt. The generator previously mentioned, which weighed 32 pounds, has a specific weight of approximately 43 pounds per kilowatt. A six-kilowatt generator (30 volts at 200 amperes) which weighs 42 pounds, has a specific weight of seven pounds per kilowatt, approximately one-sixth that of its predecessor. By doubling the rated speed of the generator making the minimum speed approximately 4,400 rpm, it has been possible to obtain further reductions. At this writing, it appears that a 12-kw (30-volt 400-ampere) generator can be produced in a total weight of 50 pounds which will be a specific weight of slightly more than four pounds per kilowatt, less than one-tenth that of its predecessor. These accomplishments have been made without requiring any increase in space on the accessory section of the engine. It is one of the minor miracles of the war.

PROGRESS IN DESIGN OF D-C MOTORS

Corresponding progress in the design of d-c motors also is being made, but it is much slower. Better progress has been made in the design of intermittent-duty motors which are used for such applications as retraction of landing gear, operation of wing flaps, and engine cowl flaps.

The increase in electric loads is having the expected effect on electric systems. That which was used during the 1920's and 1930's was a 12–15-volt system in which the battery was the predominant element. The generator was installed merely to keep the battery charged. As the load increased, it was found that doubling the operating voltage to 24–30 volts would permit the use of approximately double the power rating with very little penalty in weight. For example, the 15-volt 50-ampere generator mentioned was changed to a 30-volt generator at an increase of only two pounds, making its total weight 34 pounds. The weight of wiring was reduced somewhat. Therefore, twice the power was made available at an actual saving in weight. As the rating of generators has increased, the importance of the battery has decreased until the generator is now the predominant element.

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The importance of the battery has decreased to such an extent that there has been a very active development for small engine-generator units which provide power on the ground and which are a substitute for batteries in aircraft. These auxiliary engines fill a gap in the engine line which will have wide application after the war. There have been many engines of the three-quarter- to three-horsepower rating built for commercial usage, and there have been many of much higher rating, but the intermediate class of 5 to 25 horsepower has been neglected. These auxiliary power plants fill this need with lightweight economical units which should have wide application for a variety of purposes. For example, one 15-horsepower unit weighs 85 pounds or seven pounds per horsepower, which is much lighter than any of the commercial engines hitherto produced. Further progress in this development is possible.

USE OF HIGHER-VOLTAGE SYSTEM

As the size of aircraft increases, it is inevitable that the 24–30-volt system must give way to one of higher voltage. Use of the higher-voltage system will permit tremendous saving in wiring weight, because conductors can be utilized to their maximum current capacity, and because the current required for a given amount of power is reduced. In the large aircraft which will follow in the postwar era, this change in system voltage makes possible a saving in wiring weight alone of more than one ton.

There has been much discussion as to the form which this higher-voltage system would take. The 24–30-volt system now used is direct current. The new system can be a higher-voltage direct current, for example, 110-volt, or it can be a radical departure and can utilize alternating current. The electrical industry is prepared for either. D-c 110-volt equipment has been developed, and likewise a-c equipment designed for a frequency of 400 cycles per second is also available. Astounding progress has been made in the latter. Intermittent-duty motors have a specific weight of approximately one pound per horsepower at ratings as low as eight horsepower. Continuous-duty motors of this frequency obtain a specific weight of one pound per horsepower at approximately 25-horsepower ratings. Design indicates that it is possible to build a 1,000-horsepower 400-cycle motor in the volume occupied by the ordinary waste basket. Such a motor will weigh not more than 400 pounds. At the same time the efficiency and power factor of these motors is surprisingly good. Apparently, this is due to the fact that the number of pounds in a piece of equipment decrease faster than the power loss in watts per pound increases. In practically all cases the efficiency of aircraft electric equipment compares favorably with its commercial counterpart, despite its handicap in size and weight.

POSTWAR TRENDS

As a result of these developments, the electrical industry is ready to serve the aviation industry, regardless of the trend which the latter may take. Lighter, cheaper, more reliable, and more efficient apparatus is available for any airplane from the one owned by the private individual to the great transoceanic air liners which will cross any ocean. It is quite likely that there will be a potential market for a few hundred of these transoceanic passenger liners. They will carry more than 100 passengers, and the problem of serving food to those passengers is one which is ideally answered by an electric-power system. The cooking load alone surpasses the requirements for the largest military aircraft insofar as the electric system is concerned. This type of load is anticipated, because it is believed that such luxury passenger liners as will develop in the postwar era will contain provisions for good meals in sumptuous style. More comfortable and brighter lighting will also be cause for higher electric loads. Longer-range radio equipment will contribute. This will be an ideal application for a-c equipment now being perfected by the electrical industry.

In the private airplane market, there is quite likely to be room for more than 300,000 aircraft. These will be sold to the same class of people as those who now own motorboats for their summer sport. Electric apparatus has many advantages for such aircraft, since it will be more available and less expensive than competitive types of accessory equipment.

Between these two extremes of aircraft design will be a reasonable market for transport aircraft. This market will not be so large as many enthusiasts imagine, simply because an airplane travels very rapidly. Whereas approximately seven trains are required to maintain a daily schedule between Chicago and Los Angeles and return, one airplane can accommodate the same schedule. Since the airplane does accomplish its mission in such short time, it means that the return on the investment will be correspondingly high. Therefore, it can be expected that the electrical market in the aviation industry will continue to be one of specialties. Quantities will be small, but performance requirements will be high. Since the return on the investment is high, it can be expected that a higher cost on the special electric apparatus will be justified. A transport airplane costs approximately five dollars per pound and thus far the private airplanes cost more than three dollars per pound. Electric apparatus can be evaluated on the same basis.

However, the accomplishments in the electrical industry for aviation will affect practices in widely different lines. Designers for aircraft electric equipment have learned new methods of getting more power out of each cubic inch of electric equipment, they have learned to utilize cooling most advantageously, they have learned that brushes can be worked harder, they have learned to develop and use new materials which will withstand higher temperatures, and they have learned new techniques with regard to bearings. All of these advances will be available for the design of electric apparatus for other applications, whether it be for personal, household, or industrial use.

The use of light materials is another possible improvement in postwar electric apparatus. Designers concerned with aircraft equipment are familiar with the advantages of aluminum and magnesium in the construction of end frames and other supporting portions of electric equipment. This know-how can be transferred to other types of equipment to make lighter and cheaper apparatus.

The 400-cycle development mentioned in this article may have applications in special tools and in emergency power units which are not dependent on the industrial electric system. In any case, where weight is an advantage, this system will prove its worth.

All in all it is believed that the advances which have been made by electrical designers for a specific use in aircraft will prove to have widespread and immediate benefit to designers of other apparatus, whether it be for an electric shaver, a household washing machine, or an industrial enterprise.

Photo courtesy American Airlines

INSTITUTE ACTIVITIES

AIEE Joins SAE and NASC on Aeronautical Standards

Preparation by AIEE of an informative report dealing with the fundamental characteristics of aircraft electric systems and including sections on general system layouts, system voltages and frequencies, power supply, utilization and conversion devices, distribution systems and cable circuits, control switching and protective devices, and fault-current calculations has been decided upon. This decision was reached at meetings held in September and October in New York and at Wright Field in conjunction with the Society of Automotive Engineers, the National Aircraft Standards Committee, and the National Electrical Manufacturers Association.

Participation of AIEE in the formulation of standards for aeronautical electric equipment was commenced early this year when a plan for joint efforts with other groups instigated by the Standards committee was endorsed by the board of directors, and a liaison representative, J. R. North (F '41) assistant electrical engineer, Commonwealth and Southern Corporation, Jackson, Mich., was appointed. Subsequently, meetings with SAE, NASC, and NEMA, as well as with the Army Air Forces and the Bureau of Aeronautics were held at which the respective fields of activities of the affected groups were defined. It was agreed that the particular function of AIEE would be to set up such fundamental electrical standards as methods of rating and performance characteristics of electric equipment and devices, test codes and methods of demonstrating specified performance, fundamental characteristics of aircraft electric systems, and methods of calculation.

These problems have been divided among suitable subcommittees of the air transportation committee for solution. Those subcommittees which have been listed tentatively by D. R. Shoults (M '42) committee chairman, are: aircraft electric systems; aircraft electric rotating machinery; aircraft electric control and protective devices; aircraft wires and cables; aircraft transformers, rectifiers, capacitors, and miscellaneous static devices; aircraft lighting; and aircraft electric instruments.

Considerable work concerning the determination of preferred standard voltages for aircraft rotating electric equipment already has been done during the past year by an air transportation subcommittee under the chairmanship of J. D. Miner, Jr. (M '42) engineering manager, Westinghouse Electric and Manufacturing Company, Lima, Ohio. It is expected that a proposed standard will be approved shortly for trial use.

Future AIEE Meetings

Winter Technical Meeting
New York, N. Y., January 22–26, 1945

North Eastern District Meeting
Buffalo, N. Y., April 25–26, 1945

Summer Technical Meeting
Detroit, Mich., June 25–29, 1945

SECTION

Electronics in Peacetime Discussed in Philadelphia

Some of the ways the wartime electronic developments which have enabled utilization of ever higher frequencies will be employed successfully, and the confines set upon them by economic considerations were discussed by William C. White (M '30) head of the electronics section of the General Electric Research Laboratory, Schenectady, N. Y., before the AIEE Philadelphia Section, recently.

The extension of broadcasting and communication techniques more than tenfold upward on the spectrum of electromagnetic radiation since the war has opened up many additional frequency channels to radio and made practical such new elements as sharply directed beams with small antenna structures, Mr. White said.

With the relaxation of man power and material restriction after victory, Mr. White foresees immediate activity in the promotion of frequency modulation and television broadcasting. Since there always have been more groups interested in entering the broadcasting field than there have been suitable available frequency channels, Mr. White looks to FM broadcasting to break that bottleneck. He believes that hundreds of such stations will be put into operation as fast as they can be manufactured. Expansion of television is foreshadowed, he believes, by the fact that enough applications for transmitting-station licenses have been filed to assure regular evening programs for most metropolitan areas.

Aside from advances in radio, many new industrial developments of electronics have become technically possible, but some are economically unsound, he said. As an example he cited electronic heating, which is heat in one of its most expensive forms and, therefore, limited in usefulness. Although uneconomical for drying low-cost bulk material, its cost can be justified for a product of high unit value when time is an important factor and selective heating necessary, he declared.

Prohibitive cost also may bar many ingenious appliances from the home, Mr. White warned in mentioning one which will open a garage door for a car at the sound of its horn, or at a certain sequence of headlight flashes. However, he added, no one seriously would consider paying $250 for the contrivance.

Wilmington Subsection Plans Winter Program

A discussion of "Power Supplies for Arc Welding" and a sound film, "The Story of A-C Arc Welding," presented by R. F. Wyer of the General Electric Company, Schenectady, N. Y., comprised the program of the first regular meeting of the new Wilmington Subsection of the AIEE Philadelphia Section. Approximately 50 AIEE members, local members, and guests attended the meeting held during the first part of October.

Meeting programs for the new Subsection have been planned for the next three months. Scheduled are addresses by E. L. Harder (M '41) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., on "A-C Generator Voltage Regulation"; by S. C. Killian (A '42) of Delta Star Electric Company, Chicago, Ill., on "Substation Design and Fuse Co-ordination"; and by E. H. Alexander (M '43) General Electric Company, on "Industrial Motor Control."

Officers of the Subsection are:

Chairman: Kennard Finder (M '37) E. I. duPont de Nemours and Company.

Vice-chairman: R. G. Rudrow (M '41), Atlas Powder Company.

Secretary: Henry Evans (A '32), Delaware Light and Power Company.

Treasurer: W. A. Thomas (M '43), E. I. duPont de Nemours Company.

Executive committee: H. E. Houck (M '40), E. I. duPont de Nemours Company; E. R. Street (A '33), Delaware Power and Light Company; Joseph Kunst (A '43), Dravo Corporation; and M. G. Young (A '41) University of Delaware, Newark.

Chairman of membership committee: C. F. Magee (M '44), E. I. duPont de Nemours Company.

Chairman of program committee: F. T. Bear (M '31), Delaware Power Company.

Chairman of related activities committee: E. M. Schwyter (A '36), H. Fletcher, Brown Vocational High School.

PERSONAL

J. L. Hamilton (A '15, F '21) assistant vice-president, Century Electric Company, St. Louis, Mo., has been appointed 1944–45 chairman of the Lamme Medal committee of which he has been a member since 1942. Mr. Hamilton, who was born September 24, 1883, in Morrisville, Mo., received the degree of bachelor of science in electrical engineering from the University of Missouri in 1904. From 1904 to 1915 he was associated with the Emerson Electric Manufacturing Company, St. Louis, in general electrical and mechanical designing. He was made manager of electrical and mechanical designing in 1913. In 1915 he joined the Century Electric Company as chief engineer and in 1934 was made assistant vice-president. From 1920 to 1940 he was a member of the board of directors of the company. Mr. Hamilton was elected AIEE vice-president for the South West

District 7 in 1940 and was a member of the board of directors from 1940 to 1942. His other Institute activities include service on the committee on electrical machinery for 1926–27, and from 1932 to 1942 (chairman 1936–38); and on the committee on domestic and commercial applications, 1940–43. He is the author of many technical papers and inventor of electrical and mechanical apparatus. He is a member of the American Society for Testing Materials, the National Industrial Conference Board, and the American Management Association.

J. E. Housley

J. E. Housley (A '19, M '39, F '43) district power manager, Aluminum Company of America, Alcoa, Tenn., has been appointed 1944–45 chairman of the AIEE committee on electrochemistry and electrometallurgy of which he has been a member since 1939. Born January 9, 1893, in Knoxville, Tenn., Mr. Housley was graduated from the University of Tennessee with the degree of bachelor of science in electrical engineering in 1915. He joined the Aluminum Ore Company, East St. Louis, Ill., in 1915 as apprentice electrical engineer and in 1917 became head electrical engineer. In 1921 he was made assistant power superintendent. During 1922 he was electrical sales engineer for the Aluminum Company of America, Kansas City, Mo., but in 1923 he returned to the Aluminum Ore Company to take charge of a reconstruction program. Returning to the Aluminum Company of America, Alcoa, as assistant district electrical superintendent in 1924, he was made superintendent of power in 1927. In 1943 he was named district power manager. An active AIEE member, Mr. Housley served as Section chairman of the East Tennessee Section for 1938–39, on the AIEE membership committee, 1940–41, and the industrial power applications committee for 1943–44. He was elected AIEE vice-president for the Southern District 4 in 1941. He is a frequent contributor to technical periodicals.

A. C. Monteith (A '25, M '40) manager, industry engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed 1944–45 chairman of the AIEE Standards committee of which he has been a member since 1941. Mr. Monteith was born in Brucefield, Ontario, Canada, April 10, 1902, and received the degree of bachelor of science from Queens University in 1923. He joined the Westinghouse Company as central-station engineer in 1924 and in 1938 was made manager of the central-station section. In 1941 he became manager of the industry engineering department. Author of a number of technical papers he received honorary mention for the best paper in engineering practice in the 1937 AIEE prize awards. He has served on the following AIEE committees: power generation, 1938–43 (chairman, 1942–44); protective devices, 1940–42; Standards, 1941–44.

D. R. Shoults (A '35, M '42) industrial engineering department, General Electric Company, Schenectady, N. Y., has been appointed 1944–45 chairman of the AIEE committee on air transportation of which he has been a member since 1942. Mr. Shoults was born June 23, 1903, and received the degree of bachelor of science in electrical engineering from the University of Idaho in 1925. He entered the test course of the General Electric Company and, completing it in 1928, was assigned to the materials handling section of the industrial department. In 1929 he was transferred to the industrial manufacturers section and in 1940 to the aviation section. In this latter connection he spent several months with the Royal Air Force in England. In 1940 Mr. Shoults received the national prize award for the best paper in engineering practice. He is the author of other technical papers and a member of the Institute of Aeronautical Sciences.

E. W. O'Brien (M '37) vice-president of W. R. C. Smith Publishing Company and managing director and editor of *Southern Power and Industry*, Atlanta, Ga., has been appointed 1944–45 chairman of the committee on Student Branches of which he has been a member since 1942. Born June 20, 1897, in Phenix, West Warwick, R. I., he received the degree of bachelor of science in electrical engineering from Brown University, the degree of master of science in mechanical engineering from the Sheffield Scientific School, and the degree of mechanical engineer from Yale University. From 1918 to 1922 he was an instructor at Brown University, Providence, R. I., and in 1922 joined the faculty of the Sheffield Scientific School, New Haven, Conn., he was employed as consulting engineer by Jenks and Ballou, Providence, from 1925 to 1927. In 1927 he became editor of the *Southern Power Journal* and in 1933 managing director of the latter and of *Southern Power and Industry*. He was made vice-president and director of the W. R. C. Smith Company in 1936. Mr. O'Brien was chairman of the AIEE Georgia Section for 1941–42. He is a member of Sigma Xi, Tau Beta Pi, the Society for the Promotion of Engineering Education, and the American Society of Mechanical Engineers.

J. G. Brainerd (M '39) professor, Moore School of Electrical Engineering, and chairman of the division of physical sciences of the graduate school of the University of Pennsylvania, Philadelphia, has been appointed 1944–45 chairman of the AIEE committee on basic sciences of which he has been a member since 1940. Professor Brainerd was born August 7, 1904, in Philadelphia, and received his bachelor of science degree from the University of Pennsylvania in 1925 and the degree of doctor of science in 1934. Since 1925 as instructor and assistant professor he has been a member of the faculty of the Moore School, and in 1941 he was appointed associate professor. At present he also is engaged in a number of war research projects. From 1935 to 1937 he was associated with the Public Works Administration as engineer, assistant state director, and consultant of the power division. Professor Brainerd is coauthor of "Ultrahigh Frequency Techniques" and of "High-Frequency Alternating Currents" and author of a number of technical papers. He has edited two volumes of the *Annals* of the American Academy of Political and Social Sciences. He is AIEE representative to the recently established *Quarterly of Applied Mathematics* and is a member of the Institute of Radio Engineers and the American Academy of Political and Social Sciences.

F. B. Jewett (A '03, F '12) vice-president in charge of development and research, American Telephone and Telegraph Company,

E. W. O'Brien

J. L. Hamilton

D. R. Shoults

A. C. Monteith

New York, N. Y., retired on September 30, 1944. He was graduated from Throop Polytechnic Institute in 1898. In 1902 he received a doctor of philosophy degree from the University of Chicago and, in subsequent years, honorary degrees from various institutions including New York University, Harvard University, and the Case School of Applied Science. During the last year of his studies at the University of Chicago, Doctor Jewett acted as research assistant and in 1902 he became an assistant in physics and electrical engineering at the Massachusetts Institute of Technology, Cambridge. He entered the engineering department, American Telephone and Telegraph Company in 1904, and in 1908 he became transmission and protection engineer. In 1912 Doctor Jewett joined the Western Electric Company, New York, as assistant chief engineer, advancing to chief engineer in 1916 and vice-president in 1921 following his service in the United States Army during the first World War as a lieutenant colonel in the Signal Corps. He returned to the American Telephone and Telegraph Company in 1925 as vice-president in charge of development and research and in the same year was appointed president of the Bell Telephone Laboratories, New York, resigning from the latter position in 1940 to become chairman of the board of directors. Doctor Jewett is president of the National Academy of Sciences, a past president of AIEE, and has been a recipient of the Edison, Faraday, Franklin, and John Fritz medals.

Gerard Swope (A '99, F '22) honorary president, General Electric Company, New York, N. Y., resigned on September 8, 1944. Mr. Swope was graduated from the Massachusetts Institute of Technology in 1895 with a bachelor-of-science degree in electrical engineering. He also holds honorary doctor-of-science degrees from Rutgers University, 1923; Union College, 1924; and Washington University, 1932; a doctor-of-laws degree awarded by Colgate University, 1927; and a doctor-of-engineering degree from the Stevens Institute of Technology, 1929. He began his engineering career as a helper at the General Electric Company, Chicago, Ill., in 1893. In 1895 he joined the Western Electric Company, Chicago, as a design engineer, becoming general manager of the power-apparatus engineering department in 1906, general sales manager in New York in 1908, and vice-president and director in 1913. After serving in the United States Army during World War I, Mr. Swope was appointed president of the International General Electric Company, New York, and was made president of the General Electric Company in 1922. Following his retirement in 1940, he continued to serve as honorary president. Mr. Swope was the recipient of the Hoover Gold Medal in 1942.

M. J. Kelly (A '26, F '31) director of research, Bell Telephone Laboratories, New York, N. Y., has been elected executive vice-president of that company. Doctor Kelly was graduated from the University of Missouri in 1914 and in 1918 received the degree of doctor of philosophy from the University of Chicago. In the latter year he entered the engineering department of the Western Electric Company, New York, and in 1925 joined the Bell Telephone Laboratories as a research physicist, becoming director of research in 1936. **A. B. Clark** (M '19, F '30) director of systems development, has been elected a vice-president of that company. Mr. Clark was graduated from the University of Michigan in 1911 and then entered the American Telephone and Telegraph Company, New York. He transferred to the Bell Telephone Laboratories in 1934 and in 1940 became director of systems development. **R. L. Jones** (A '11, F '31) director of apparatus development, has also been made a vice-president of the Bell Telephone Laboratories. A graduate of the Massachusetts Institute of Technology in 1909, Doctor Jones entered the employ of the Bell Telephone Laboratories in 1911 and in 1928 became director of apparatus development.

W. A. Smith (A '23) formerly chief engineer, Ohio Brass Company, Barberton, has been appointed consulting engineer. Mr. Smith's first position was with Westinghouse, Church, Kerr, and Company, New York, N. Y., in 1902. He did insulator inspecting and testing in New York and Ohio for the Pacific Gas and Electric Corporation, San Francisco, Calif., from 1904 until 1906 and in 1907 became an automobile dealer, Smith Brothers, Los Angeles, Calif. Mr. Smith has been with the Ohio Brass Company since 1916 except for a period from 1924 until 1931 when he acted as an independent engineer. **J. J. Taylor** (A '37) of the engineering department has been appointed chief engineer. Mr. Taylor received his engineering degree from the University of Alberta, Canada, in 1928. From 1924 to 1926 he was a draftsman for the Canadian government in Brazeau Forest, Coldspur, Alberta. He took the test course of the General Electric Company, Peterborough, Ontario, Canada, in 1928 and then was placed in the induction-motor-design department. Mr. Taylor joined the Canadian Ohio Brass Company, Niagara Falls, Ontario, in 1930 and was transferred to Barberton, Ohio, in 1931.

E. H. Kifer (A '09, M '13) formerly business manager and engineer, San Antonio (Tex.) Board of Education, has been made general manager of the City Public Service Board, San Antonio. Mr. Kifer was graduated from the University of Wisconsin in 1908 with a degree of bachelor of science in electrical engineering. His career in public utilities began in 1903 with the Madison (Wis.) Gas and Electric Company and later he was employed by the San Antonio Public Service Company and the Binghamton (N. Y.) Gas Company. He became associated with the San Antonio Board of Education in 1937. **W. B. Tuttle** (M '30) formerly chairman of the board of directors, San Antonio Public Service Company, has been made chairman of the board of the City Public Service Board. Mr. Tuttle's first position was with the Consolidated Gas Company of New Jersey in 1896. He left to join the American Light and Traction Company, New York, N. Y., but returned to the Consolidated Gas Company in 1898. In 1918, after working for the San Antonio Traction Company and the San Antonio Gas and Electric Company, he was employed by the San Antonio Public Service Company. He was appointed chairman in 1935.

C. F. Hawker (A '20, M '25) chief engineer, Armstrong Cork Company, Lancaster, Pa., has been elected vice-president in charge of manufacture. Mr. Hawker was graduated from Ohio State University in 1917. In the same year he entered the employ of the Carolina Power and Light Company, Florence, S. C., but left to join the United States Army. He became resident engineer on construction for the Phoenix Utility Company, Hartsville, S. C., in 1919 and later assistant electrical engineer, Dayton (Ohio) Power and Light Company. In 1923 he was electrical engineer in charge of electrical design and construction, E. W. Clark Corporation, Columbus, Ohio, and successively held positions with the Commonwealth Power Corporation, Jackson, Mich., in 1926 and the Tennessee Electric Power Company, Chattanooga, in 1929. Mr. Hawker joined the Armstrong Cork Company in 1930. He was made assistant chief engineer in 1936 and chief engineer in 1937.

C. L. Kinsloe (A '08, M '13) professor and head of the department of electrical engineering, the Pennsylvania State College, State College, has retired. A graduate of Central State Normal School in 1899, Professor Kinsloe received his bachelor-of-science degree from the Pennsylvania State College in 1903 and the degree of master of science in electrical engineering in 1907. After six years in the engineering departments of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and the Philadelphia (Pa.) Electric Company, he began his teaching career as an instructor in electrical engineering, Western University of Pennsylvania, in 1906. In 1907 he joined the staff of the Pennsylvania State College as acting head of the department of electrical engineering. Two years later Professor Kinsloe was made head of the department.

F. M. Williams (A '21, M '28) general installation engineer, Western Electric Company, Inc., New York, N. Y., retired on October 1. Mr. Williams is a graduate of the University of Minnesota, having received a bachelor-of-arts degree in 1905 and a degree in electrical engineering in 1909. He joined the student course of the Western Electric Company, Chicago, Ill., in the latter year and in 1910 was made equipment engineer. In 1922 he became assistant superintendent of equipment engineering and in 1923, superintendent. In 1927 Mr. Williams was transferred to New York as general installation engineer.

R. C. Disque (M '20) dean of engineering, Drexel Institute of Technology, Philadelphia, Pa., has been named acting president of the institute. A graduate of the University of Wisconsin in 1903 with a bachelor-of-law degree, Professor Disque joined the staff as an instructor in electrical engineering in 1908, after receiving the degree of bachelor of science in electrical engineering, and in 1913, became assistant professor. In 1919, following three years of service in the United States Army during which he attained the rank of major, he was appointed professor of engineering at Drexel Institute, and in 1925 he became dean.

L. B. LeVesconte (A '36, M '43) district engineer, central-station division, Westinghouse Electric and Manufacturing Company, Chicago, Ill., will become assistant professor of electrical engineering and chief engineer of the network-calculator laboratory, Illinois Institute of Technology, Chicago. Mr. LeVesconte joined the Westinghouse Company in East Pittsburgh, Pa., in 1927 as a member of the student course. Subsequently, he was employed in the switchboard engineering department, the relay engineering department at Newark, N. J., and in 1937 was transferred to Chicago as district engineer.

Paul MacGahan (A '02, F '42) development engineer, Westinghouse Electric and Manufacturing Company, Newark, N. J., has retired. A graduate of Columbia University in 1896 with a degree in electrical engineering, Mr. MacGahan attended the graduate student course at Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., until 1897 when he was placed in the detail and supply engineering department. He was put in charge of instrument and relay engineering in 1905 and in 1925 became development engineer.

A. P-T. Sah (A '35, M' 36) president of the National University of Amoy, Changting, Fukien, China, has been decorated by the Chinese Government and awarded the plaque of the Order of the Brilliant Star for his meritorious administration of a national university during war time. Doctor Sah is also the recipient of the first Medal of Honor given by the Chinese Institute of Electrical Engineers for contributions to the science of electrical engineering.

L. A. Hawkins (A '03, M '13) executive engineer of the research laboratories, the General Electric Company, Schenectady, N. Y., has been appointed to the board of trustees of the newly established Illuminating Engineering Society Research Fund. **P. H. Daggett** (A '08) dean of the college of engineering, Rutgers University, New Brunswick, N. J., will also serve as a member of the board.

C. O. Bickelhaupt (M '22, F '28) colonel and commanding officer of the Eastern Signal Corps Unit Training Center, United States Army, Fort Monmouth, N. J., has been promoted to the rank of brigadier general. General Bickelhaupt was a vice-president of the American Telephone and Telegraph Company, New York, N. Y. when called to active duty with the Army in 1941.

F. G. Logan (A '35) chief development engineer Ward Leonard Electric Company, Mount Vernon, N. Y., has been elected vice-president and manager of research and development. Mr. Logan became associated with the Ward Leonard Company in 1925 as advertising manager and since 1929 has been engaged in development work. He was made a director in 1937, manager of research and development in 1940, and manager of the regulator division in 1941.

T. D. Reimers (M '36) electrical superintendent of the Hudson Avenue generating station, Consolidated Edison Company of New York, Inc., New York, has joined the Sheldon Service Corporation, Long Island City, N. Y., as the engineering manager. Mr. Reimers had been with the Consolidated Edison Company since 1927 and was appointed electrical superintendent in 1943.

P. L. Bellaschi (A '29, F '40) development engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has arrived in South America for a tour in which he will study her expanding electrical needs and inform leading South American industrialists, technical-research men, and educators of recent scientific developments in the United States.

F. B. Johnson (M '37) formerly apparatus engineer, Commonwealth Edison Company, Chicago, Ill., has been appointed assistant chief testing engineer. **J. W. Baring** (M '41) formerly head starting engineer, has been made apparatus engineer.

A. J. Haskens (M '44) formerly electrical engineer for the supervisor of shipbuilding, United States Navy, San Pedro, Calif., has joined the Lukas-Harold Corporation, Indianapolis, Ind., as a research and development electrical engineer.

W. A. Furst (A '13, M '27) formerly general contract manager, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed district representative, storage battery division, Philco Corporation, Pittsburgh, Pa.

F. E. Bodine (A '43) manager of the Salt Lake City office, Westinghouse Electric and Manufacturing Company, Salt Lake City, Utah, has been transferred to San Francisco, Calif., as manager of the company's San Francisco office.

J. A. Mahoney (M '36) major, United States Army, Washington, D. C., has been promoted to the rank of lieutenant colonel. Colonel Mahoney was formerly with the Bell Telephone Laboratories, Inc., New York, N. Y.

E. A. Hertzler (A '35) formerly in charge of the electrical engineering laboratory, Pratt Institute, Brooklyn, N. Y., has been appointed director of war research, United Electronics Company, Newark, N. J.

Dudley Sanford (A '25) assistant treasurer, Union Electric Company of Missouri, Webster Groves, has joined the general office staff of the Union Electric Company, St. Louis, as executive assistant.

H. R. Arnold (A '31) electrical engineer, Bureau of Ships, United States Navy Department, Washington, D. C., has been made an engineer in the Office of the Co-ordinator of Inter-American Affairs, Washington.

OBITUARY

S. Edgar Whitaker (A '96, M '13) partner, George H. Kingsley and Company, certified accountants, New York, N. Y., died August 10, 1944. Mr. Whitaker was born on June 3, 1870, in Medford, Mass. He was graduated from Boston University in 1890 with the degree of bachelor of arts and in 1893 received a master of arts degree from Boston University and a bachelor of science degree in electrical engineering from the Massachusetts Institute of Technology. Mr. Whitaker entered the business world in 1888 as a member of the partnership of Whitaker and Locke, which supplied textbooks to students of Boston University. In 1893 he became a bookkeeper for the assignees of Grosvenor and Richards, Boston, Mass., and in 1894, after a month in the dynamo room of the Massachusetts Institute of Technology, Boston, he entered the meter-testing department of the General Electric Company, Lynn, Mass., but left in 1896 to start a private business as electrical engineer and contractor in Fitchburg, Mass. In the ensuing years, between 1898 and 1916, Mr. Whitaker was employed by the Norfolk (Mass.) Southern Street Railway Company, the Norton and Taunton (Mass.) Street Railway Company, and the Portland and Yarmouth (Me.) Electric Railway Company; as consulting engineer, Burnett, Cummings, and Company, Boston; as office manager and assistant to the secretary, American Society of Mechanical Engineers, New York; and as consulting engineer to various clients, including the Russian Commission. In 1919 he became a cost accountant for the Philadelphia District Ordnance office, and most of the rest of his career was spent in accounting. He did public accounting in 1922 and 1923; was with the Harold B. Barnett Company, public accountants, New York, from 1927 to 1930; and was certified as a public accountant in 1935. Mr. Whitaker was a member of the Taylor Society.

Clem A. Copeland (A '97, F '40) retired member of the Los Angeles, Calif., Bureau of Power and Light, died August 18, 1944. Mr. Copeland was born in Goshen, Ind., on July 21, 1870, and was graduated from Cornell University in 1896. From 1888 to 1890 he was in the employ of the Electric Rapid Transit Street Car Company, San Diego, Calif., and then became secretary of the Westinghouse Incandescent Electric Light System of San Diego. Upon his graduation from Cornell University, he was made resident electrical engineer of the Copper Queen Mining Company, Bisbee, Ariz., and later, assistant electrical engineer of the Edison Electric Company, a predecessor of the Southern California Edison Company of Los Angeles. In 1897 Mr. Copeland was appointed associate professor in charge of electrical engineering, Stanford University, Calif. but in 1901 returned to the engineering profession as superintendent of distribution, Southern California Edison Company. Subsequently, he became a consulting engineer in Los Angeles, 1904; research engineer, Pacific Electric Railway Company of Los Angeles, 1909; assistant hydroelectric engineer, Pacific Gas and Electric Company, San Francisco, Calif., 1910; and valuation engineer, H. M. Rylleaby Company, Chicago, Ill., 1914. He entered the employ of the City of Los Angeles in the Bureau of Power and Light in 1916 and when he retired in 1940 was head of the research and records section. Mr. Copeland was the author of many papers and was a member of the Los Angeles Engineering Council of Founder Societies.

Louis T. Grant (A '99, M '18) retired consulting engineer and major in the United States Army during the World War I, died

July 15, 1944. Major Grant was born in Richmond, Va., November 27, 1860, and in 1885 was apprenticed to the Mather Electric Company, Manchester, Conn., as an erecter on the roads. He was with the Mather Electric Company until 1888 when he entered the shops of the Thomson-Houston Company, Lynn, Mass. In 1890, after an interval with the Union Switch and Signal Company, on the New York and New England railroad, he became engaged in erection work for the Thomson-Houston Company and was sent to Saltillo, Mexico, where he became manager of the Saltillo Electric Light Company. For the next 21 years Major Grant was employed in various engineering capacities in Nicaragua, Hawaii, Costa Rica, the Philippines, and Papeete, in Tahiti. He returned to the United States in 1912 as a consulting engineer in San Francisco, Calif., and in 1917 was commissioned as a captain in the United States Army. He was promoted to major in 1918 and returned to civilian life in 1921 as manager of the 12th district, United States Veterans Bureau, San Francisco. From 1924 until his retirement in 1936, Major Grant acted as a consulting engineer in San Francisco.

Daniel C. Green (M '26) chairman of the board, Cleveland (Ohio) Pneumatic Tool Company, died July 2, 1944. Born on November 16, 1884, in Patriot, Ind., Mr. Green was graduated from Purdue University in 1908. He was employed by the San Diego (Calif.) Consolidated Gas and Electric Company in 1909. In 1910 he was made manager of the Oregon Power Company at Albany, Ore., and in 1911 was transferred to Marshfield, Ore., in the same capacity. From 1913 to 1915 he was connected with the Everett (Wash.) Gas Company as vice-president and general manager and then joined the Utah Power and Light Company, Salt Lake City, as division manager. Subsequently, he was with the Fort Smith (Ark.) Light and Traction Company, the Utah Light and Traction Company, Salt Lake City; the Western Colorado Power Company, Salt Lake City; and the Electric Bond and Share Company, New York, N. Y. In 1933 Mr. Green was elected president of the Middlewest Utilities Company, Chicago, Ill., and in 1936 he was appointed chairman of the Central Service Corporation, Chicago. He became chairman of the board of the Cleveland Pneumatic Tool Company in 1942.

Neil Alan Dey (A '36) lieutenant in the Royal Canadian Navy, formerly in the engineering department, Dominion Cutout Company, Ltd., Toronto, Ontario, Canada, died August 8, 1944. Lieutenant Dey was born on January 24, 1905, in Wooler, Northumberland, England, and was graduated from Trent College in 1922 and from Faraday House in 1929. In 1922 he was an apprentice engineer for C. A. Parsons and Company, Newcastle-Upon-Tyne, England. In 1930, after completion of the graduate student test course, General Electric Company, Schenectady, N. Y., he assisted in the erection of an outdoor substation and hydroelectric installations for the Canadian General Electric Company. Lieutenant Dey became testing and development engineer for the Dominion Cutout Company, Ltd., and the Dominion Carbon Brush Company, Ltd., in 1931. He entered the Naval service in 1943.

Miles Ludlow Wright (A '25) in charge of testing laboratories, Public Service Company of Northern Illinois, Chicago, died August 9, 1944. He was born in Raymonds, Ohio, July 15, 1888, and, after taking the four-year electrical engineering course at Ohio State University, he was employed by the Jeffry Manufacturing Company, Columbus, Ohio, in 1908, in the armature-winding department and the testing department. He went to work for the North Shore Electric Company, Evanston, Ill., in 1909 and became superintendent of the meter departments of the Illinois Northern Utilities Company, Dixon, Ill., in 1912. Mr. Wright had been with the Public Service Company of Northern Illinois since 1913 and was put in charge of testing laboratories in 1935.

Laurence West Tower (A '36) Southwestern manager, Phelps Dodge Copper Products Corporation, Houston, Tex., died recently. Born in Providence, R. I., on July 6, 1896, Mr. Tower attended Brown University. In 1917 he joined the United States Navy, serving until 1920 when he became assistant superintendent of production, American Electric Works, Phillipsdale, R. I. He became associated with the Phelps Dodge Corporation in 1923 in the Habirshaw cable and wire division and about 1935 was transferred to Houston. Previously, he had been located in New Orleans, La., and Birmingham, Ala. Mr. Tower was a member of the Petroleum Electrical Suppliers Association and the Houston Engineers Club.

Alfred L. Oklund (A '35, M '40) design engineer, the Louis Allis Company, Milwaukee, Wis., died August 19, 1944. Born in Superior, Wis., on November 18, 1905, he was graduated from the Milwaukee School of Engineering in 1932 with the degree of bachelor of science in electrical engineering. After graduation he became an instructor in physics and later professor in charge of physics at the same school. He became connected with the Louis Allis Company in 1937 as an engineer. Mr. Oklund was a member of the General Engineering Council Committee and the Milwaukee School of Engineering committee on advance degrees in certificates.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on September 29, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Aita, F. S., Anaconda Wire & Cable Co., Sycamore, Ill.
Beisber, M. F., transformer engr., Line Material Co., San Francisco, Calif.
Benowitz, Captain, Signal Corps, Dayton, Ohio
Blim, Philip, electronics engr., New Britain Machine Co., New Britain, Conn.
Crawford, J. M., asst. elec. engr., Shawinigan Water & Power Co., Montreal, Que., Can.
Gilford, Edward, asst. chief, elec. div., Cox & Stevens, New York
Grayheal, T. D., asst. prof. of elec. engg., Univ. of California, Berkeley, Calif.
Green, N. J., secy., National Electric Coil Co., Columbus, Ohio
Heilmann, R. K., asst. chief engr., Connecticut Tel. & Electric Div., Meriden, Conn.
Hicks, B. C., protection engr., Shawinigan Water & Power Co., Montreal, Que. Can.
Kiltie, O., section engr., General Elec. Co., Fort Wayne, Ind.
Kreft, H. H., chief engr., Standard Transformer Corp., Chicago, Ill.
MacLean, G. D., mgr., Marlborough Electric Power Board, Blenheim, New Zealand
Martin, T. J., captain, Air Corps, Wright Field, Dayton, Ohio
Mellish, A. W., engr., Univ. of California, San Diego, Calif.
Morrison, G. K., asst. mgr., RCA., Harrison, N. J.
Muehlig, R. E., repair supt., Westinghouse E. & M. Co., South Boston, Mass.
Mulligan, J. E., asst. prof. of elec. engg., Mass. Inst. of Tech., Cambrge, Mass.
Nason, E. P., Lieut., Corps of Engrs., Ft. Belvoir, Va.
Nonken, G. C., engr., General Elec. Co., Pittsfield, Mass.
Parks, C. E., relay engr., Public Service Co. of Indiana, Inc., Indianapolis, Ind.
Pembleton, F. W., industrial engr., R. B. N. Co., Logansport, Ind.
Perry, H. L., elec. engr., General Elec. Co., New York
Plotz, R. S., member of technical staff, Bell Tel. Labs., Inc., New York
Robert, L. W., consulting engr., Bona Allen Bldg., Atlanta, Ga.
Ross, Hugh, mgr., switchgear section, Canadian General Elec. Co. Ltd., Toronto, Ont. Can.
Sage, Darrow, mechanical operating engr., Public Service Elec. & Gas Co., Newark, N. J.
Schmidt, August, application engr., General Elec. Co., Schenectady, N. Y.
Scott, J. N., elec. designer, Charles T. Main, Inc., Boston, Mass.
Shemer, A. M., telephone engr., Bell Tel. Labs., Inc., New York
Silliman, H. G., senior elec. engr., City of Seattle, Seattle, Wash.
Small, R. H., instructor, New York University, New York
Smith, W. P., Lieut., Inspector of Naval Material, Schenectady, N. Y.
Soule, C. E., electrician, Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Spease, J. F., district engr., General Elec. Co., Portland, Ore.
Stroup, C. L., elec. engr., Hubbard & Co., Chicago, Ill.
Sukachoff, A. S., elec. engr., York & Sawyer, New York
Treece, C. C., elec. engr., Louisiana Power & Light Co., Monroe, La.
Vail, C. R., instructor in elec. engg., Duke Univ., Durham, N. C.
Wallace, G. A., associate prof. of elec. engg., McGill Univ., Montreal, Que. Can.
Walmsley, A. W., design engr., Electro Metallurgical Co., Niagara Falls, N. Y.
Walther, Austin, elec. engr., C. C. Moore & Co., San Francisco, Calif.
Wendelken, W. W., elec. supt., Westinghouse E. & M. Co., Pittsburgh, Pa.
Williams, A. J., chief of elec. div., Leeds & Northrup Co., Philadelphia, Pa.
Winemiller, H. K., engr., Commonwealth Edison Co., Chicago, Ill.
Wortz, L. J., group foreman, Detroit Edison Co., Detroit, Mich.
Wright, R. R., associate prof. of elec. engg., Virginia Poly. Inst., Blacksburg, Va.

47 to grade of Member

The board of examiners, at its meeting on October 19, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Doyle, H. K., operating supt., Dallas Power & Light Co., Dallas, Texas
Frampton, A. H., asst. chief elec. engr., The Hydro-electric Power Commission of Ontario, Toronto, Can.
Ruth, E. S., chief engr., Edwards & Co. Inc., Norwalk, Conn.
Watts, F. W., vice-president, Great American Industries, Inc., Meriden, Conn
Winne, H. A., vice-president, General Elec Co., Schenectady, N. Y.
Wolf, H. B., Supt., Maintenance, Duke Power Co., Charlotte, N. C.

6 to grade of Fellow

To Grade of Member

Almon, C. P., chief, Power System Operations Div., Tennessee Valley Authority, Chattanooga, Tean
Bagwell, L. R., design engr., City of Houston, Houston, Texas
Barry, J. G., asst. prof. of elec. engg., Princeton University, Princeton, N. J.
Braguier, C. E., elec. engr., Ebasco Services, Inc., New York
Brouse, H. L., development engr., Crosley Corp., Cincinnati, Ohio
Dublin, L. I., elec. engr., U. S. Navy Dept., Staten Island N. Y.
Foote, B. R., research engr., Hartford Electric Light Co., Hartford, Conn.
Gammell, John, chief, electrical equipment branch, War Production Board, Washington, D. C.
Goldsmith, Arthur, Lieut., U. S. Naval Reserve, Fleet Post Office, Norfolk, Va.
Hibben, S. G., director of applied lighting, Westinghouse Lamp Div., Bloomfield, N. J.

Kersh, R. S., Houston Manager, Westinghouse E. & M. Co., Houston, Texas
Muzzillo, M. F., consulting elec. engr., New York
Nacinovich, T. P., Leading Technician, George G. Sharp, New York
Neal, C. W., transmission engr., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Sigler, E. M., application engr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Snyder, R. F., elec. engr., Goodyear Tire & Rubber Co., Akron, Ohio
Tait, W. F., asst. general manager, Public Service Elec. & Gas Co., Newark, N. J.

17 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before November 30, 1944, or January 31, 1945, if the applicant resides outside of the United States or Canada.

To Grade of Member

Anderson, W. V., A. S. Schulman Elec. Co., Knoxville, Tenn.
Ashby, C. A., Jr. (Reelection), Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Averitt, R. A. (Reelection), Gen. Elec. Co., Schenectady, N. Y.
Bauman, H. C., Chemical Const. Corp, New York, N. Y.
Bower, J. L., General Elec. Co., Schenectady, N. Y.
Branch, T. P., Rural Elect. Adm., St. Louis, Mo.
Brown, A. L., Jefferson-Travis Radio Mfg. Corp., New York, N. Y.
Carroll, J. (Reelection), Smaller War Plants Corp., Detroit, Mich.
Cooper, N. D., Westinghouse Elec. & Mfg. Co., Cincinnati, Ohio.
Cornejo R., A. (Reelection), Pub. Works Dept., Mexico, D. F., Mex.
Cotton, J. S., Federal Pr. Com., San Francisco, Calif.
Defandorf, J. L. (Reelection), Cutler-Hammer, Inc., Milwaukee, Wis.
Earle, J. W. (Reelection), General Elec. Co., Newark, N. J.
Garrison, D. (Reelection), U. S. Army, Washington, D. C.
Gemes, G. R., Electromagnetic Mfg. Co., Sydney, Aust.
Goldmark, P. C. (Reelection), Columbia Broadcasting System, Inc., New York, N. Y.
Hamilton, R. M., Austin Co., Houston, Texas
Inserstedt, G., Can. Aircraft Inst. & Accss., Leaside, Ont., Can.
Johnson, C. H. (Reelection), Gen. Elec. Co., San Francisco, Calif.
Kirkpatrick, H. J. (Reelection), Alum. Co. of Can., Ltd., Montreal, Que., Can.
Maedel, G. F. (Reelection), R.C.A. Inst., Inc., New York, N. Y.
Mahle, H. J. (Reelection), Cons. Gas Elec. Lt. & Pr. Co., Baltimore, Md.
Margetts, W. L. (Reelection), U. S. Maritime Com., Oakland, Calif.
McNicol, F. C. (Reelection), Cutler-Hammer Inc., Milwaukee, Wis.
Mellon, A., Clark Controller Co., Cleveland, Ohio
Milliken, C. S., Lockheed Aircraft Corp., Burbank, Calif.
Minard, G. W. (Reelection), Nebr. Pr. Co., Omaha, Nebr.
Montesinos y Ferrer, J. E., Antilla Sugar Estates, Oriente, Cuba
Morse, T. B., Mass. Inst. of Tech., Cambridge, Mass.
Moss, C. M. (Reelection), Westinghouse Elec. & Mfg. Co., Cincinnati, Ohio
Neale, E. K., Neale Relay Co., Inc., Los Angeles, Calif.
Potter, P. S., Iowa State College, Ames, Iowa
Rahmes, R. E. (Reelection), Western Elec. Co., Inc., New York, N. Y.
Rauber, W. F., Gen. Elec. Co., Philadelphia, Pa.
Reardon, K. N. (Reelection), West Penn Power Co., Pittsburgh, Pa.
Roys, C. S. (Reelection), Ill. Inst. of Tech., Chicago, Ill.
Rylance, J. H., National Defence Dept., Ottawa, Ont., Can.
Schiller, H., Gen. Cable Corp., Perth Amboy, N. J.
Scott, L. W., General Elec. Co., Charleston, W. Va.
Smith, E. E., E. I. du Pont de Nemours Co., Wilmington, Del.
Stadtfeld, N., Jr. (Reelection), Panama Canal, Balboa Heights, C. Z.
Temin, J. T., General Elec. Co., Lynn, Mass.
Trinkle, W. S. (Reelection), Sprague Elec. Co. & Allied Cont. Co., Philadelphia, Pa.
Verwoert, H. C. (Reelection), Gen. Elec. Co., San Francisco, Calif.
Vest, W. L., Jr. (Reelection), Western Mass. Elec. Co., Springfield, Mass.
Vinci, S. A., Lockheed Aircraft Corp., Burbank, Calif.
Volski, M. L., Eastern Air Devices Inc., Brooklyn, N. Y.
Welty, R., Rural Elect. Adm., St. Louis, Mo.

48 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Brown, J. D., Corning Glass Works, Corning, N. Y.
Dewey, M. T., Amer. Tel. & Tel. Co., Buffalo, N. Y.
Gilbert, M. M., Buffalo Nag. Elec. Corp., Buffalo, N. Y.
Hart, W. G., Gen. Elec. Co., Schenectady, N. Y.
Herzig, F. J., Com. of Mass. Dept. Pub. Util., Boston, Mass.
Miller, G. W. (Reelection), Rochester Tel. Corp., Rochester, N. Y.
Petty, H. W., Wagner Elec. Corp., Boston, Mass.
Sanderson, K. E., Draper Corp., Hopedale, Mass.
Swope, I. G., Mass. Inst. of Tech., Cambridge, Mass.
Warner, E. S. (Reelection), U. S. Engineers, Providence, R. I.
Warner, R. S., Amer. Boach Corp., Springfield, Mass.

2. Middle Eastern

Armor, C. A., Westinghouse Elec. & Mfg. Co., Cincinnati, Ohio
Bale, D. F., I-T-E Circuit Breaker Co., Philadelphia, Pa.
Bird, R. E., Lieut., R.N.V.R., Washington, D. C.
Bloom, W. F., Dayton Pr. & Lt. Co., Dayton, Ohio
Bowman, F. G., Wright Field, Dayton, Ohio
Burchfield, W. F., Jack & Heintz, Inc., Bedford, Ohio
Cohn, M. (Reelection), Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Corrigan, W. A., Delaware Pr. & Lt. Co., Wilmington, Del.
Crush, R. G., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Davis, R. K., Equipment Lab., Wright Field, Dayton, Ohio
Egee, A. H. (Reelection), E. I. du Pont de Nemours, Wilmington, Del.
Flahie, C. E., Toledo Edison Co., Toledo, Ohio
Friedrich, C. H., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Gravenstreter, P. R., Clark Controller Co., Cleveland, Ohio
Harman, N. F., Jr., B. F. Goodrich Co., Akron, Ohio
Hauenstein, C. J., Baltimore Transit Co., Baltimore, Md.
Hommel, R. E., Amer. Tel. & Tel. Co., Dayton, Ohio
Hoose, W. L., Northern Pa. Pr. Co., Towanda, Pa.
Hughes, H. M., Allis-Chalmers Mfg. Co., Pittsburgh, Pa.
Jewell, F. W., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Kautsky, N. L., Goodyear Tire & Rubber Co., Akron, Ohio
Lankford, H. B (Reelection), Penna. Water & Pr. Co., Baltimore, Md.
Lord, D. E., Naval Ord. Lab., Washington, D. C.
Mayhew, W. K., Alum. Co. of America, Cleveland, Ohio
McArthur, B. E., Alum. Co. of America, Cleveland, Ohio
Packer, W., Republic Steel Corp., Cleveland, Ohio
Payne, W. H., Jr., Howard Univ., Washington, D. C.
Ponyik, F. E., Leece-Neville Co., Cleveland, Ohio
Post, R. G., Brush Dev. Co., Cleveland, Ohio
Purcell, J. T., General Elec. Co., Philadelphia, Pa.
Ross, P. N., U. S. Navy Dept., Washington, D. C.
Schonhoff, J. A., Maryland Drydock Co., Baltimore, Md.
Snyder, W. M., U. S. Navy Yard, Philadelphia, Pa.
Story, T. H. (Reelection), Radio Corp. of America, Camden, N. J.
Swegman, W. J., Wright Field, Dayton, Ohio
Thein, C. J., Alum. Co. of America, Cleveland, Ohio
Youtz, R. V., Penna. Water & Pr. Co., Baltimore, Md.

3. New York City

Contier, E. J., Monroe Cal. Mach. Co., Orange, N. J.
Cummins, L. (Reelection), Amer. Transformer Co., Newark, N. J.
Kallor, J., U.S.N.R., New York, N. Y.
Leggio, J., Newark Sig. Corps, Insp. Zone, Newark, N. J.
Lee, E. G., Ebasco Services, Inc., New York, N. Y.
O'Grady, J. V., Syncro Machine Co., Perth Amboy, N. J.
Sampson, J. L., Bell Tel. Labs., Inc., New York, N. Y.
Schmidt, A. H., U. S. Navy Dept., Newark, N. J.

4. Southern

Coleman, W. G., Gen. Elec. Co., Atlanta, Ga.
Frischhertz, R., Times Picayune Pub. Co., New Orleans, La.
Jemison, R. M., Interstate-Elec. Co., Shreveport, La.
Juge, A. F., Higgins Ind., Inc., New Orleans, La.
Pettyjohn, J. G., Gen. Elec. Co., Knoxville, Tenn.
Rounds, N., U.S.M.C. Air Station, Cherry Point, N. C.
Vogel, C. J., Tenn. Valley Auth., Chattanooga, Tenn.
Weaver, J. A., Tampa Shipbldg. Co., Tampa, Fla.
Williamson, R. B., Williamson Sales Co., Shreveport, La.

5. Great Lakes

Abrell, C. W., White City Elec. Co., Decatur, Ill.
Anderson, K. C., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Beck, A. E., Richmond Elec. Ltg. & Pr. Plant, Richmond, Ind.
Becken, R. W., Interstate Pr. Co., Cass Lake, Minn.
Berghs, C. J., Pub. Serv. Co. of Northern Ill., Glencoe, Ill.
Gaulke, E. C., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Johnson, G. D. S., Valier Coal Co., Valier, Ill.
Marley, G. W. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Parez, J., Harnischfeger Corp., Milwaukee, Wis.
Rana, M. B., Gen. Elec. Co., Lansing, Mich.
Rypstra, B., Wilcox-Gay Corp., Charlotte, Mich.
Schoenig, L. W., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Sheridan, W. T., Univ. of Minn., Minneapolis, Minn.
Stellish, J. E., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Van Valkenburg, H. V., Anaconda Wire & Cable Co., Chicago, Ill.
Walker, J. R., Ex Cello Corp., Detroit, Mich.

6. North Central

Lang, J. T., Pub. Serv. Co. of Colo., Denver, Colo.
Neff, E. N., Pub. Serv. Co. of Colo., Denver, Colo.
O'Rourke, H. T., Mountain States Tel. & Tel. Co., Denver, Colo.
Wagner, W. W., Army Air Forces, Denver, Colo.

7. South West

Biesele R. L., Jr., Southern Meth. Univ., Dallas, Texas
Boddie, J. R., Humble Oil & Ref. Co., Baytown, Texas
Brewer, R. Y., S.W. Bell Tel. Co., Wichita, Kans.
Brown, C. P., Beech Aircraft Corp., Wichita, Kans.
Caudry, J. L., Texas Elec. Serv. Co., Fort Worth, Texas
Geen, J. M., Gulf States Util. Co., Beaumont, Texas
Gode, R. Z., Pub. Serv. Co. of Okla., Tulsa, Okla.
Laughlin, C. E., Gulf States Util. Co., Beaumont, Texas
McKey, D. B., Radio Station WKY, Oklahoma City, Okla.
Newth, H. R., Texas Elec. Serv. Co., Fort Worth, Texas
Oertli, F. J., Guarantee Elec. Co., St. Louis, Mo.
Pickett, M. J., Texas Elec. Serv. Co., Fort Worth, Texas
Powers, W. J., Amer. Tel. & Tel. Co., Tulsa, Okla.
Puls, A. E., Rural Elect. Adm., St. Louis, Mo.
Read, N. K., Texas Elec. Serv. Co., Fort Worth, Texas
Sullivant, J. E., Smoky Hill Army Airfield, Salina, Kans.
Uehlinger, J. A., Gulf States Util. Co., Port Arthur, Texas
Welborn, J. L., Houston, Lighting & Pr. Co., Houston, Texas

8. Pacific

Beck, H. R., Lockheed Aircraft Corp., Burbank, Calif.
de Beaumont, G., Production Materials Co., Los Angeles, Calif.
Eckart, K. G., Los Angeles Shipbldg. & Drydock Corp., San Pedro, Calif.
Galchutt, E. H., Graybar Elec. Co., Inc., Los Angeles, Calif.
Goodrich, T. M., Pasadena Mun. Lt. & Pr. Dept., Pasadena, Calif.
Hoag, R. O., Alum. Co. of America, Torrance, Calif.
Huskison, E. J., Cent. Ariz. Lt. & Pr. Co., Phoenix, Ariz.
Jones, J. N., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Mason, M. A. (Reelection), Los Angeles Water & Pr. Dept., Los Angeles, Calif.
O'Connor, R. A., Cons. Aircraft Corp., San Diego, Calif.
Quebedeaux, T. C., North Amer. Avia., Inc., Inglewood, Calif.
Spencer, J. C., Public Utilities Dept., Alameda, Calif.
Turner, J. M., U. S. Navy, San Francisco, Calif.
Wright, E. C., U. S. Navy Radio & Sound Lab., San Diego, Calif.
Wright, F. M., North Amer. Avia., Inc., Inglewood, Calif.

9. North West

Argo, E. G., Bonneville Pr. Adm., Vancouver, Wash.
Egan, L. B., Mont. Pr. Co., Great Falls, Mont.
Finley, K. G., Washington Water Pr. Co., Spokane, Wash.
LeVasseur, J. A., Mont. Pr. Co., Great Falls, Mont.
Martin, T. M. C., Bonneville Pr. Adm., Portland, Oreg.
O'Gara, E. H., Gen. Elec. Co., Spokane, Wash.
Roach, T. E., Northwestern Elec. Co., Portland, Oreg.
Shelton, C. A., Anaconda Copper Min. Co., Great Falls, Mont.
Webster, C. H., Alum. Co. of America, Spokane, Wash.
Windust, G. B., Pacific Tel. & Tel. Co., Portland, Oreg.

10. Canada

Archibald, M. C., Montreal Engg. Co., Ltd., Montreal, Que., Can.
Holden, S. R., Bell Tel. Co. of Can., Toronto, Ont., Can.
Jackson, A. H. C., Can. Johns-Manville Co. Ltd., Asbestos, Que., Can.
Katakoff, J., Montreal Engg. Co. Ltd., Montreal, Que., Can.
Kitchen, W. H. J., Elec. Lieut., R.C.N.V.R., Midland, Ont., Can.
Mochon, J. N., Gov. of Quebec, Montreal, Que., Can.
Mooney, R. L., Square D Co. of Canada, Ltd., Montreal, Que., Can.

Elsewhere

Adams, R. G., Mex. Tel. & Tel. Co., Mexico, D. F., Mex.
Briem, E., Municipal El. Lt. & Pr. Works, Reykjavik, Iceland
Cervantes, I., Emp. de Tel. Ericsson, S. A., Mexico, D. F., Mex.
Chadha, N. S., Sub-Divisional Officer, Works Section, Indian Command
del Real, J. F., Const. y Maq. S. de R. L., Mexico, D. F., Mex.
Eurle, A. C., Mex. Tel. & Tel. Co., Mexico, D. F., Mex.
Fasen, T., A., Mex. Lt. & Pr. Co., Mexico, D. F., Mex.
Ferrer, C., B., Ing. Mecanico Electricista, Mexico, D. F., Mex.
Fowler, I. D., Univ. of Queensland, Brisbane, Aust.
French, J. E., Sydney Tech. Coll., Ultimo, Aust.
Garcia T., C., National Road Comm., Mexico, D. F., Mex.
Kenney, A. J., General Elec. Co., Ltd., Coventry, England
Lelivs, R. G., Cia. Ref. de Azucar, Vina del Mar, Chile, S. A.
Margain, F., M. I., Contractor, Mexico, D. F., Mex.
Marshall, R. S., R.N.V.R., Leith, Scotland
Pena C., G., Nat. Def. Ministery, Mexico, D. F., Mex.
Popoca, C., Mex. Lt. & Pr. Co., Mexico, D. F., Mex.
Portal M., M. A., Com. Nac. de Irrigacion, Mexico, D. F., Mex.
Ramirez B., J., Mex. Lt. & Pr. Co., Mexico, D. F., Mex.
Rangel G., H., Cuban Tel. Co., Havana, Cuba
Reidl, O., Emp. de Tel. Ericsson, S. A., Mexico, D. F., Mex.
Rodriguez R., G., Nat. Bur. of Pub. Works, Mexico, D. F., Mex.
Serrano A., S., Public Lighting Office, Mexico, D. F., Mex.

Total to grade of Associate
United States and Canada, 135
Elsewhere, 23

OF CURRENT INTEREST

Chicago Conference Presages Expanding Electronic Applications

Strong indications of accelerated activity in the field of electronics after the war were much in evidence at the National Electronics Conference held in Chicago, Ill., October 5–7, 1944. More than 2,100 were registered at the conference, and capacity audiences attended the technical sessions and other activities, somewhat overtaxing some of the facilities of the Medinah Club where it was held. The conference was sponsored jointly by the Illinois Institute of Technology, Northwestern University, and the Chicago Sections of the Institute of Radio Engineers and AIEE, with the co-operation of the Chicago Technical Societies' Council. A second conference already is being planned by the same sponsors for October 1945.

A total of 50 papers was included in the 16 technical sessions of the busy 2½-day program, covering the subject matter of electronics including latest advances in theory and some of the newest applications, insofar as these could be revealed under wartime conditions. The program included also an opening general session, two luncheons (one sponsored by the Institute of Radio Engineers and one by the AIEE Chicago Section), and a banquet. Some 1,100 persons attended the banquet and more than 1,000 each of the luncheons.

Topping the list of general subjects in number of sessions and papers was industrial electronic applications. Three sessions were devoted entirely to that subject; in addition, there was a session on industrial radiography, and a session on electronic measurements and controls dealt mostly with industrial applications. A session on ultrahigh-frequency heating reviewed progress in industrial use of electric energy at these frequencies for heat-treating and dehydrating purposes.

Although only one session was devoted exclusively to the ultrahigh frequencies, most of the sessions involved ultrahigh-frequency techniques and equipment to some extent. Two sessions outlined the latest advances in the theoretical realm, with heavy emphasis on the ultrahigh frequencies.

One session was devoted to radio, and one presented the latest advances in television, which is expected to develop rapidly after the war. Other topics to which one session each was devoted were: power applications; aids to medical science; tube development; telephone applications; and aeronautical applications.

With a few exceptions, all papers presented will be printed and bound together in the "Proceedings of the National Electronics Conference," which will be made available to those who attended.* In addition, plans are being made for publishing some of the papers in *Electrical Engineering*.

Discussing activities at the National Electronics Conference (left to right) Earl Abbot, (A '37) General Electric Company, Chicago, Ill.; J. E. Hobson (M '41) and P. G. Andres, Illinois Institute of Technology, Chicago; W. C. White (M '30) General Electric Company, Schenectady, N. Y. Doctors Hobson and Andres were respectively chairmen of the conference executive committee and arrangement committee; Mr. Abbott was a member of the arrangement committee; and Mr. White, who is chairman of the AIEE committee on electronics, spoke at the conference luncheon arranged by the AIEE Chicago Section

BEAL ADDRESSES OPENING SESSION

An address "Electronic Research Opens New Frontiers," by Ralph R. Beal, assistant to the vice-president in charge of RCA Laboratories, sounded the keynote of the conference at the opening general session. A. B. Bronwell (A '34), chairman of the conference program committee, presided, and Dean Ovid W. Eshbach (F '37) of the Northwestern University Technological Institute, extended the official welcome to those attending.

"Research, and more research, is the order of the postwar world," declared Mr. Beal in his address. He presented an appraisal of some of the important scientific contributions to the winning of the war and predicted some of the probable directions of future electronic research.

"During the past four years science has been mobilized into a co-operative effort unprecedented in all history," said Mr. Beal. "Throughout America, industrial research and engineering have been geared in perfect harmony. Internationally, the same co-operation has been in operation. Science, therefore, has been forged into an all-powerful wheel that turns to generate victory. . . Out of the preparedness of our research scientists and engineers in electronics, have emerged new and vital weapons and new means of speeding industrial output. Radio, no longer confined to dots and dashes as in the last war, became, thanks to electronic research, the eyes and ears of our fighting machine, the voice of our high command, the directing force behind our anti-aircraft guns, the unerring guides of warplanes and warships and the means of communicating swiftly across every ocean and across every frontier.

"Electron tubes flash facsimiles of maps, documents, and photographs over great distances to aid Allied strategy. Radio broadcasting stations are voices of liberty, informing and uniting our people. Yet these are only a few of the achievements of radio and electronics. When the full story is permitted to be told, it will be an astounding chapter of scientific accomplishment."

Discussing research in the ultrahigh-frequency regions, Mr. Beal said in part: "Research in electronics and vacuum-tube circuits is bringing into use the vast radio spectrum which lies in the frequency range from 30 to 30,000 megacycles. These are the very high, ultrahigh and superhigh frequency ranges, the characteristics of which open new horizons of tremendous potentialities for exploration. . . .

* Others interested in the conference papers may obtain the "Proceedings" at two dollars per copy. To minimize bookkeeping, the conference committee would appreciate remittances with orders, which should be forwarded to Professor P. G. Andres, Illinois Institute of Technology, 3300 Federal Street, Chicago 16, Ill. It is important that orders be entered as soon as possible, as the number of copies of the "Proceedings" printed will be determined largely by advance orders.

"A service that has yet to be developed in the very high-frequency spectrum is facsimile broadcasting—radio transmission and reception of the printed page, illustrations and diagrams. This will add a service of record to the services of sound and sight to the home. . . .

"Radio and electronic developments are an indispensable aid to man in his conquest of the skyways—in attaining speed and safety in air travel. They have opened realms of vast scope to the airplane by affording freedom of movement over land and sea. . . ."

Speaking of new aids to air traffic that may be expected in the future, Mr. Beal predicted that: "Collision-prevention apparatus will indicate obstructions that may loom in the airplane's course and afford ample warning for changing the direction or elevation of the airplane to avoid collision. Electronic means for controlling the airplane itself and for connecting the controls of the airplane into guiding radio systems so that it may fly to its destination automatically are entirely feasible in the postwar period."

Turning to television, Mr. Beal declared that "into the development of this marvel of the age has gone more concentrated research than into any other modern development. . . Television has the greatest promise of service to the public of any development in the art and science of radio. With a television receiver in your home, you will become an eyewitness to interesting events and entertainment beyond your immediate horizon. From your living room, you will see the world pass in review.

"Theater television also is being prepared as a great news service. For the first time in the centuries of theater history, a method has been devised for bringing to theater audiences the thrills and drama of actual events as they occur at a distance in real life. Electronic research has made it possible to produce pictures in motion upon a theater-size screen."

Still another service with "fabulous possibilities" is industrial television, Mr. Beal said. "This application envisages the use of radio sight as the 'eyes' of factories, the means of co-ordinating and controlling giant manufacturing enterprises, and the means also of looking into places that otherwise might be inaccessible or dangerous to man. Industrial television may be used by the plant manager to observe critical operations. It may be used to follow the flow of materials and observe progress of work. It may be used in chemical-reaction chambers to make visible complicated chemical processes."

Characterizing the electron microscope as the most revolutionary laboratory tool of the 20th century, Mr. Beal said that "there are more startling inventions which have come out of radio-electronic research—developments with a wide range of industrial applications in which electron tubes play a vital role." Among the many industrial applications that he described in some detail, was what he called radiothermics—the industrial use of high-frequency power to generate heat. He pointed out how high-frequency heat had made possible the all-wood airplane and continued: "Informed observers foresee a broad field for high-frequency heating in the furniture industry after the war, particularly in the manufacture of curved laminated sections. . . ."

Mr. Beal closed with an "urgent plea that our industrial research laboratories continue to work hand in hand with our Army and Navy in peace as they have done so magnificently in war. Let us through science put new power behind the wings of the dove of peace."

WHITE ADDRESSES AIEE LUNCHEON

An address "Electronics in Industry," by W. C. White (M '30), chairman of the AIEE committee on electronics, keynoted the discussions on industrial electronic applications at the conference. Mr. White spoke at the luncheon sponsored by the AIEE Chicago Section over which Chairman R. C. Ericson (M '41) of that Section presided.

"There is much hope that all of the new ideas and developments that have resulted from the war effort can be put to use to produce new devices to minimize the postwar recession in business volume," said Mr. White. "The big question and likewise the big problem involved is how quickly can some of these new ideas and developments be brought into commercial use."

Citing as specific examples high-frequency induction heating, operation of d-c motors on an a-c supply through electron tube control, and the use of large sealed-off rectifiers as typical examples, Mr. White called attention to the long delay between laboratory development and active commercial utilization of electronic devices in the past. As the most important reasons for this he cited the following:

1. The cynicism and stagnation of initiative that accompany a business depression.
2. Mental resistance to change.
3. The "vicious circle in new developments"—the difficulty of producing a satisfactory design without operating experience, which experience is difficult to get without first producing a satisfactory design.
4. Higher first cost and maintenance expense.
5. Ignorance of what electronic devices can do and how they operate.
6. The relatively short tube life.
7. Variation in characteristics between individual tubes of the same type.

Turning to the present, Mr. White called attention to the indispensable role that electronics equipment is playing in America's record-breaking war production, declaring that "this industrial tool has been directly responsible for saving millions of man- and machine-hours, and millions of pounds of critical materials since Pearl Harbor."

"As a result of the war," he continued, "many new military electronic devices have progressed from the idea stage to actual use in a remarkably short period of time, sometimes only a matter of months. In the light of the retarding factors mentioned, it is interesting to study this accelerated pace and try to arrive at the reasons back of it. Many of these are clearly apparent:

1. In the place of the deadening mental attitude that accompanies depression, there is instead the atmosphere of energy and a determination to get results and get them quickly.
2. In place of the normal feeling of resistance to change, there is the certain knowledge that unless we get ahead and keep ahead of our enemies we are licked.
3. The so-called vicious circle of trial and error does not exist or is taken in stride as a necessary cycle.
4. Cost and expense are minor factors if the equipment even promises to help win the war.
5. One can only guess as to how many thousands or maybe tens of thousands of men and women during the period of the war have been given intensive training in the operation, care, and maintenance of a multitude of electronic devices. Much good publicity has also helped to minimize the ignorance factor.

It is obvious that a few of these factors are not just temporary but will carry over into the postwar period and, therefore, represent net gains."

Concerning the future, Mr. White discussed some of the factors that might shorten the elapsed time between the laboratory and extended commercial use. First it must be recognized that electronics to the industrial engineer is another tool to add to his kit to use in conjunction with other well-developed methods. Another thing that must be kept in mind is that in most industrial-applications electronic devices are just one part of a larger piece of apparatus.

The place where the first trial application is to be made should be one where a high first cost and a high maintenance cost can be justified, and should be in the hands of a "friendly customer." Tubes should be designed for long life and should be operated conservatively, and continuity of operation must be designed into the equipment.

In closing, Mr. White emphasized that the problems he had discussed are not ones that cast any doubts on the future of electronics. "That future is assured. The point is we want to bring about that coming expansion in the characteristic American way which means: just as rapidly as possible."

ADMIRAL REDMAN AND GENERAL INGLES ADDRESS BANQUET "ELECTRONICALLY"

Although neither Rear Admiral Joseph R. Redman, chief of naval communications, nor Major General H. C. Ingles, chief signal officer, could attend the conference, both addressed the banquet through the medium of the electronic wire recorder. Major Lenox R. Lohr, president, Museum of Science and Industry, Chicago, delivered the feature address of the banquet, on "Triggers to Mass Action." The banquet program was opened by J. E. Hobson (M '41) chairman of the conference executive committee; after brief remarks he introduced President H. T. Heald of the Illinois Institute of Technology who presided throughout the remainder of the program.

"To say that electronics has played a major role in the war and will continue to play such a role, is a conservative statement," began Admiral Redman in his wire-recorded talk. "The scientists of the Allies have pitted their wits against the scientists of the Axis in a constant battle to devise new and effective articles of warfare and devices to deny (or counter) the enemy's use of his new weapons; this is particularly true in the field of electronics, and we believe that *our* scientists are winning their end of this war! Not only are the scientists waging this war, but also the manufacturers; the manufacturers are engineering the scientist's developments to meet the rigid requirements in the field and are then producing the articles rapidly and in the huge quantities that are needed by the combat personnel. . .

"It is no new story to you that electronics now provides the United States Fleet with vitally important instruments. Guns are controlled by electronics; ranges and deflections are computed and applied, the guns trained and elevated, and the guns fired—all by electronics. No military organization can hope for success without fast, reliable,

and secure means of communications; electronics has provided the Navy with these means of projecting the will of the commander-in-chief over both small and wide expanses of the globe. There are many other types of electronic devices used by the Navy; these applications are far too numerous to mention but, by the aid of all these electronic devices and with American boys operating them, the Navy has a record which is the envy of every navy of the world. . .

"The present war has demonstrated that we must depend upon our ability to utilize scientific developments, and that no nation from now on can hope to win a victory unless it is in possession of adequate scientific resources, both in men and in facilities. Obviously electronics is the basis of many of these scientific weapons. As the Navy Officer responsible for providing many electronic devices to the Fleet, I would welcome from you suggestions as to the manner in which we can best co-ordinate our efforts so that we will maintain and improve our leadership."

General Ingles began his recorded talk with a message of congratulation. "During the past three years," he said, "the Army Signal Corps has had to ask for some virtually impossible things from the electronic engineers of America. We needed what amounts to a new industry—the mass production of radio transmitters, in quantities that were known in peacetime only for radio receiving sets. We insisted that the performance standards of a fixed broadcasting station be embodied in two-way radio communications equipment functioning in tanks, command cars, and jeeps moving through dust and mud, and in pursuit airplanes and bombers flying over the clouds. We specified push-button tuning for many types of transmitters and receivers, with crystal control of frequencies. We wanted small sets with big outputs. We wanted versatile sets designed with a restricted choice of components. We demanded that radio accomplish miracles of which the founders of radio never dreamed —such miracles as aircraft detection, pin-point navigation, and finding the exact direction and range of a target.

"All of these remarkable things—and some others which I may not even mention—have been accomplished. And their accomplishment has had an important part in bringing about the success of our forces in the field. . .

"The necessary instruments were available to our commanders in the field because the engineers in laboratories and factories at home found ways to meet our impossible military characteristics and to conform to our very exacting military specifications. To do this meant not only hard work but more than a touch of inspiration, for our electronic development during the war has been carried out on the very borderline of physical science. The electronic industry is hardly a generation old. Yet in the last fiscal year the Army Signal Corps alone accepted deliveries of $2,355,000,000 worth of signal equipment, most of it built around electronic tubes. . .

"There are still plenty of interesting problems to exercise the proved ingenuity and resourcefulness of our electronic physicists, designers, engineers, and production men. More than ever, now, we must ask you to speed up the cycle between the laboratory prototype and the production line. A great many new technical ideas exist which should shorten the war considerably as soon as we can bring them out in the form of standard equipment. We need to put these devices in the hands of fighting men quickly, so that more of them will come home sooner to share in postwar life to which we are all looking forward."

CONFERENCE COMMITTEES

The executive committee responsible for planning the conference and carrying it to completion was headed by J. E. Hobson (M '41) of Illinois Institute of Technology. Beverly Dudley of the McGraw-Hill Publishing Company, Inc., served as secretary of the committee, and A. Crossley as treasurer. Other members of the committee were: P. G. Andres, W. M. Ballenger (M '38), R. E. Beam (A '42), A. B. Bronwell (A '34), C. A. Crowley, L. T. Hearson (A '31), R. H. Herrick, C. S. Roys, W. O. Swinyard, S. E. Winston.

Professor Bronwell served as chairman of the 21-member program committee, Professor Andres as chairman of the 10-member arrangements committee, and Mr. Dudley as chairman of the 12-member publications and publicity committee.

WAR PROGRAM . .

Help on AAF Problems Asked by National Inventors Council

A third series of military inventive problems occupying the National Inventors Council recently was released for general distribution by permission of the War Department. The problems contained in this latest series have sprung from the needs of the Army Air Forces. In inviting submission of solutions the Council pointed out that partially satisfactory answers to most of them are already available. Proposals should be forwarded to: National Inventors Council, Department of Commerce, Washington 25, D. C. The following is the list released by the Council:

1. A lightweight reliable simply installed thrust meter for aircraft installation, combined with a torque meter if possible.

2. A shock absorber that does not require the use of synthetic packing to retain the fluid in the strut.

3. Shimmyproof free-swiveling castered wheel and tire.

4. An accurate simple cable-tension reading instrument.

5. A control cable having a coefficient of expansion close to that of aluminum alloys used in the aircraft structures or an equivalent mechanism which will take up cable slack.

6. A high-precision low-friction bearing that does not involve the use of balls or rollers.

7. The development of a suitable shock mount to permit the installation of a gun camera to a caliber 0.50 machine gun to permit the photographing of objects during the time that the gun is being fired.

8. Small lightweight gasoline engine, either two or four cycle, capable of reasonable continuous operation utilizing 100-octane aviation gasoline, which may be started and operated at temperatures as low as —65 degrees Fahrenheit. Rating should be between one and five horsepower.

9. An independently operated heating unit for sea-level operation, capable of continuous operation at —65 degrees Fahrenheit for a period of eight hours. Unit should weigh one pound or less per 1,000 Btu per hour output and must deliver clean nontoxic heated air.

10. A liquid or paste good for at least 12 hours' service which will prevent the formation of ice on airplane surfaces.

11. Methods of fabricating quartz hairsprings and diaphragms for use in watches, aneroid barometers, altimeters, air-speed indicators, and rate-of-climb indicators.

12. A device for the quick release of a cargo parachute from the cargo upon contact of the cargo with the ground. This is desirable to prevent the dragging of the cargo on the ground.

13. Positive parachute-opening device, to provide automatic opening at a definite altitude above the ground.

14. Improved form-fitting flexible comfortable parachute pack for reduced weight and bulk and with tendency toward premature release eliminated, also improved wearing qualities desirable.

15. Harness with improved quick-releasing hardware, reduced weight and bulk, and increase in comfort.

16. Low-cost aerial delivery parachutes. Must withstand 200 miles per hour air-speeds.

17. Parachute-drop test instruments: Load recorder for parachute openings. Means for recording precise time of opening and rate of descent.

18. Parachute canopy redesign to reduce weight and bulk without impairing present performance.

19. A stable parachute equal in strength and simplicity of construction to present hemispherical type.

20. A release and exchange mechanism for two targets suitable for exchanging targets without loss of equipment at high speeds.

21. A tow target "hit indicator" to indicate hits and the direction and magnitude of misses for fixed, flexible, and turret aerial gunnery practice fire.

22. A tow target capable of being towed at high speeds and producing a low drag.

23. An extra flexible high-strength 1/8-inch-diameter target-towing cable that will not "birdcage."

24. Machine for running breakdown experiments on heating elements incorporated in electrically heated flying clothing. Clothing includes jackets, trousers, gloves, and shoes.

25. Design dependable thermostats for control of heating clothing to operate on direct current, small enough to be used in gloves and boots.

26. Development of an electroplating method for the deposition of a lead–indium alloy containing approximately 4 per cent indium.

27. Development of methods or apparatus for establishing the quality of glue joints in wood without testing to destruction.

28. Development of a material with the electrical properties and heat-resistant characteristics of mica.

29. Automatic ground-speed measuring devices.

30. Compact, light, and durable two-speed or variable drive for geared superchargers.

31. Shockless two-speed propeller-drive mechanism.

32. Practical variable-diameter propeller for maximum performance at sea level and extreme altitude.

33. Practical two-position or variable compression-ratio control.

34. Simple and light detonation indicator for installation in airplane.

Signal Corps in Vanguard of Normandy Invasion

Pieced together by the War Department from individual crew reports the story of the Signal Corps' part in the Normandy invasion is one of courage, endurance, and quick-wittedness under almost constant fire from enemy ground forces and strafing from the air. Neither the proximity of large oil dumps and high explosives likely to be set afire by enemy shells nor the inconvenience of having the tires shot off their jeeps delayed nor deterred the crews from their task of laying wire. The wire network kept pace with the invasion.

Signal Corps infantry crews put ashore with the first invasion forces as well as air-

borne Signal Corps men landed by parachute and glider soon had a labyrinth of intercommunication lines set up for the dispersed invasion units. Hundreds of local lines ran along every country lane and crisscrossed orchards and barley fields. French cement poles, usually placed much too close to the roads to permit passage of Army vehicles, had to be used for stringing the wires at first. Gradually these were replaced by larger wooden poles shipped from American lumber yards. Small "rapid" pole lines were erected at intervals between the larger poles to take up the slack of the innumerable dangling wires so that they would not be cut by trucks skidding on the muddy country roads.

As fast as the enemy knocked out the lines the signalmen repaired them. All telephone wires were checked four times daily by trouble shooters, using portable Signal Corps telephones, and so efficient was this service that the trouble shooters could inform the wire patrol crews of the exact point between two poles at which a break occurred. Once the break was located, a lapse of but a few minutes brought a repairman to the spot.

The air-borne Signal Corps men, veterans of the Sicilian and Italian campaigns, laid 3,000 miles of wire and repaired 85 radios while the Allied action was at its height in Normandy.

AAF Sells Surplus Equipment. Raw and fabricated materials, standard parts, motors, hardware, fabrics, precision tools, equipment, and other surplus stocks are being offered for public sale by the Army Air Forces. Companies interested in the materials desiring to have their names placed on the active bidders list should write to: Army Air Forces, Air Technical Service Command, Midwestern Procurement District, Municipal Airport, P. O. Box 117, Wichita, Kans.

War Department Offers Speakers Through New Speakers Branch

A new Army Speakers' Branch which will make available army combat veterans from all theaters, especially the Southwest Pacific and China-Burma-India theaters, who will speak before major industrial groups and similar organizations, has been opened in Washington, D. C., according to an announcement issued by the War Department.

Colonel Warren J. Clear, General Staff Corps, who served as Military Attache to the American Embassy in Tokyo, Japan, for nine years preceding the war, is chief of the Speakers' Branch. Colonel Clear is a veteran of Bataan and Corregidor and returned a short time ago from a visit to the combat fronts in France as an observer for the Under Secretary of War. Other speakers currently available include: Lieutenant Colonel Charles W. Kerwood, air ace; Lieutenant Colonel Timothy A. McInerny, Infantry, recently returned from the European theater; Lieutenant Colonel Roswell P. Rosengren, Engineers Corps, commander of the Supreme Headquarters Allied Expeditionary Forces Courier Service in the invasion; Lieutenant William S. Spector, Medical Administrative Corps, a veteran of Guadalcanal; and Sergeant Meyer Bernstein, Infantry veteran.

Large organizations, related either directly or indirectly to the prosecution of the war, may request speakers through Captain Alvin Grauer, Speakers' Branch, Industrial Service Division, Bureau of Public Relations, War Department, Pentagon Building, Washington, D. C.

Means of Protecting Military Equipment From Fungi Studied

A fungus farm for studying means of combating the threat of wear and breakdown inherent in colonies of fungi collecting on delicate military equipment has been established by the General Electric Company in its laboratories in Schenectady, N. Y.

The danger is particularly great in the tropics where the warm moist atmosphere favors fungus growths. Fungus colonies feed on electrical insulation, often causing short circuits. They clog machinery and throw off a by-product which forms an acid strong enough to corrode metallic and electrical parts.

Since the natural conditions which retard the growth of fungi—humidity 75 degrees below atmospheric humidity, a surface spotlessly free of dust, and watertight casing—are almost impossible to reproduce in the theaters of war, the company's scientists are experimenting with waxes, varnishes, and lacquers which will have a toxic effect on the growths. Although several fungicidal varnishes have been developed, no one has been found to meet all the desired requirements. To be completely effective, a fungicide would arrest the parasitic growth, be nonpoisonous to human beings, and be noncorrosive, permanent, and colorless.

Permanency is a quality especially difficult to capture. Whereas present fungicides will continue to be effective for several months at room temperature, they lose their power in a day or two in temperatures from 120 to 140 degrees.

INDUSTRY . . . . .

Research Fellowships Established in F. B. Jewett's Name

A trust fund to finance five annual postdoctorate fellowships in physical science has been established by the American Telephone and Telegraph Company, New York, N. Y., in honor of Frank B. Jewett, retired vice-president of that company and president of the National Academy of Sciences.

The fellowships, which provide an annual honorarium of $3,000 to the holder and $1,500 to the institution which he selects, enable the recipient to devote a year or so following his doctorate to research in pure science. It normally will be awarded to those who have obtained the doctorate within the preceding year or who expect to receive that degree not later than the beginning of the next fellowship term (July 1). The awards will be made on recommendation of the Frank B. Jewett fellowship committee, consisting of seven members of the scientific staff of the Bell Telephone Laboratories, which will base its selections primarily on the demonstrated research ability of the applicant, the fundamental importance of the problem he proposes to attack, and the likelihood of his growth as a scientist.

WPB Approves Manufacture of Turbines for Soviet Union

Approval of the manufacture in this country of nine hydroelectric turbine generators for the Dnieprostroi plant in the Soviet Union has been announced by the War Production Board.

The turbines, which will replace those destroyed by the Russians when they retreated before the Germans in 1941, have a total capacity of 900,000 horsepower and will require at least four years to manufacture and install. According to the WPB, this machinery will not be provided through lend-lease but will be financed by Russia, and its manufacture will not be permitted to interfere either with wartime production or with any important phase of reconversion.

Kerite Company Stock Purchased. It has been announced that Lee Higginson Corporation has purchased all of the stock of The Kerite Insulated Wire and Cable Company, Inc., sole manufacturers of Kerite insulation, a product used in railroad, power, and telegraph services, as well as in submarine and electronic applications. The company's present policies and management will be continued, the announcement states.

OTHER SOCIETIES .

ASTM to Publish 1945 Issue of Standards in 1944

Publication of the 1945 Book of the American Society for Testing Materials Standards has been advanced a full year and the book, which is normally issued on a triennial basis, will come out in December 1944. Advancement of the publication date is the result of the heavy demand, occasioned by war production, for the

Future Meetings of Other Societies

American Society of Mechanical Engineers. Annual meeting, November 27–December 1, 1944, New York, N. Y.

American Standards Association. Annual meeting, December 8, 1944, New York, N. Y.

National Exposition of Power and Mechanical Engineering. November 27–December 2, 1944, New York, N. Y.

Institute of the Aeronautical Sciences. Fall meeting, November 1944, Dayton, Ohio; 13th annual meeting, April 1945, Detroit, Mich.

National Industrial Chemical Conference and Third National Chemical Exposition. November 15–19, 1944, Chicago, Ill.

Pacific Coast Electrical Association. Annual fall conferences: northern section, November 9, 1944, San Francisco, Calif.; southern section, November 16, 1944, Hollywood, Calif.

1942 Standards and its Supplements.

The ASTM Standards provides specifications and tests for a wide range of engineering materials and will cover 6,000 pages in three parts: metals, nonmetallic materials (constructional), and nonmetallic materials (general).

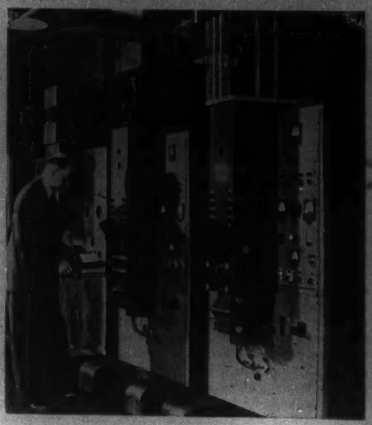
Pamphlet Describes ASHVE Research Program

Details on the 28 research projects approved by the committee on research of the American Society of Heating and Ventilating Engineers are given in a new 32-page booklet.

A brief statement of purpose is included for each project followed by a more detailed account of the technical plan covering specific objectives, type of research, and the general method of procedure. A description of the new research laboratory in Cleveland, Ohio, a list of the committee personnel, and a list of the planned projects and the research in progress also appear. The society's research is supported by members' dues, contributions, and agreements for co-operative research. Samuel R. Lewis of Chicago, Ill., has been named chairman of the research finance committee.

Specifications for Glass Insulators. A series of specifications covering various types of glass insulators, namely, Standard Tests for Pin-Type Lime Glass Insulators, Tentative Methods of Testing Glass Spool Insulators, and Tentative Specifications for Low- and Medium-Voltage Pin-Type Lime Glass Insulators, has been developed by the American Society for Testing Material's committee on electrical insulating materials. The new emergency specifications supplement these standards by covering communication and signal pin-type materials and were developed in co-operation with the Signal Corps and United States Army Specifications 71-4953.

Cold-Cathode Tube Emits 50,000-Volt Beam



A 50,000-volt beam generated in a cold-cathode tube investigates electrical phenomena ranging from the spark of an ignition system to lightning striking a transmission line in this new electronic oscillograph built by the Westinghouse Electric and Manufacturing Company for aircraft engine manufacturers, research laboratories, and electric-power companies. The beam records its story upon a fixed or rotating film which is exposed by a photoelectric control for one revolution only, although the film-drum speed is variable up to 7,000 rpm.

sence in 1940 to serve as president of the Federal Reserve Bank of Boston.

Mr. Flanders is a past president of The American Society of Mechanical Engineers and is a member of the Franklin Society. He was the 1934 recipient of the Worcester Reed Warner Medal and in 1942 shared the Edward Longstreth Medal.

The Hoover Medal was instituted by the late Conrad N. Lauer and its first presentation was made to Herbert Hoover (HM '29) in 1930 to commemorate Mr. Hoover's "civic and humanitarian achievements." Other AIEE members who have been Hoover medalists are: Gano Dunn (A '91, F '12), 1939; and Gerard Swope (A '99, F '22), 1942.

JOINT ACTIVITIES

R. E. Flanders Selected as 1944 Hoover Medalist

The Hoover Gold Medal for 1944, awarded to an engineer "for distinguished public service," has been conferred upon Ralph E. Flanders, president, the Federal Reserve Bank of Boston, Mass., and president (on leave) of the Jones and Lamson Machine Company, Springfield, Vt.

Mr. Flanders has been active in the engineering field since 1897 when he was a draftsman in Providence and Woonsocket, R. I. He received the degree of mechanical engineer from the Stevens Institute of Technology in 1932 and in subsequent years has been awarded many honorary degrees. In 1912 Mr. Flanders joined the firm of Jones and Lamson as director and manager and by 1933 had attained the presidency of that company. He was granted a leave of ab-

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

The Electric-Power Industry After the War

To the Editor:

Mr. T. G. LeClair, whose article appears in the September 1944 issue of *Electrical Engineering*, pages 338–341, entitled, "The Electric-Power Industry After the War," follows a growing practice in applying the name "electrostatic" heating to the heating of dielectric materials or materials with poor conductivity by means of radio-frequency currents. How such a misnomer was originated is difficult to understand, when one considers that the driving voltage oscillates at a rate of millions of cycles per second and at times even at hundreds of millions of cycles per second. Consider the bewilderment of the unsuspecting searcher for knowledge who may peruse a text on electrostatics from cover to cover without finding a single sentence which applies to radio-frequency heating. Although I have no concrete suggestion to offer, it seems appropriate that the AIEE Standards committee consider the problem of producing a suitable descriptive name which has a technically correct basis.

GEORGE H. BROWN (M '41)
(Research engineer, Radio Corporation of America Laboratories, Princeton, N. J.)

Industrial Research Under Free Enterprise

To the Editor:

I have read the letters in the September issue of *Electrical Engineering* commenting on "Industrial Research Under Free Enterprise" very carefully and find them very interesting.

It seems to me that your editor's note replies quite adequately to the communications of Donald G. Worth and Roy C. Dwyer.

Mr. Ford W. Harris' comments upon socialistic trends in this country remind me that our American socialists who "point with

pride" to the accomplishments of Russia generally overlook the fact that Russia, after a lot of costly experiments in Marxian socialism which resulted in the starvation of some millions of Russians, belatedly realized that human beings do not respond to efforts which tend to reduce great masses of people to common low levels but that national growth and progress can be stimulated and assured by a proper application of incentives.

The great progress in education and training and development of industrial and military establishments in Russia took place after the Russians installed effective incentives at every level of their social, economic, political, and military structures.

Our American communists and fellow travelers seem to advocate exactly the philosophy that Russia tried and found wanting, and, during exactly the period of time in which Russia has moved forward so spectacularly as the result of applying effective incentives, American democracy has been going downhill through the destruction of incentives.

Ironically enough, much of the incentive philosophy which now is accepted so broadly in Russia had its origins in the fundamental American philosophy.

Of course, there isn't the slightest justification for believing that Russia is moving away from stateism toward capitalism. She is simply applying incentives effectively to make communism work while we are destroying democracy as we destroy incentives.

I sincerely hope that your excellent publication will continue its policy of publishing controversial material. More open debate of such subjects may be the means of converting heat into light.

LOUIS RUTHENBURG

(President, Servel, Inc., Evansville, Ind.)

To the Editor:

It is probably unnecessary for me to write you, as you seem to have decided on a course of action which I think is good, but as the matter is controversial, I will let you know my reaction to two of the letters to the editor on Mr. Ruthenburg's article in the September issue of *Electrical Engineering*.

As I read Mr. Dwyer's letter I thought of suggesting that you take a poll of the membership of the AIEE on the question. From what little I know of the membership I believe that such a poll would go strongly against Mr. Dwyer. But after reading your note below it, I saw that it was unnecessary, for you intend to go placidly on your way in spite of what he wrote. I agree with you entirely on the position you have taken. It should be remembered that if a member doesn't happen to like an article that is printed in *Electrical Engineering* he doesn't have to read it, and he shouldn't set himself up to dictate what the other members should read. They are all intelligent men trained in scientific thought, and of course would consider both sides of a question.

Evidently Mr. Ruthenburg's paper hit Mr. Worth where it hurt. Since he is a Government employee, it is easy to see how he would feel; this is not the case with Mr. Dwyer, as I don't believe the Aluminum Company of America is a part of the Government as yet. But I think he should conceal his feelings as best he can, unless he is prepared to give a logical and reasonable rebuttal. Too many of the Government people seem to think that their ideas and acts should be above criticism, in fact that it is little short of sacrilege for the "common herd" to do so. To me this is a preposterous attitude which should be discouraged.

There is no necessity for any discussion of Mr. Ruthenburg's article on my part. When I read it, I thought that it was very timely; contained much food for thought and some items of information that were new and interesting to me. I was very glad to see a reference to a book on human engineering, and considered the article as a whole to be a real contribution to the subject.

As I have thought for some time that the present chaotic and generally unsatisfactory condition of this country, and even of the whole world, at the present time, has been caused by the lag of the social sciences behind what I term the material sciences, I have been greatly pleased by the papers in *Electrical Engineering* on social questions, especially on account of the men of known engineering ability who have written them. I have found them very encouraging, like a light on a dark night. However, I have noticed that they have seemed to drop off in number since we got into the war, possibly because the members are too busy with other things. This new branch of science, human engineering, interests me greatly, and I believe has some wonderful possibilities.

HAROLD L. DEYOE (A '30)

(Draftsman, service inspections and records, Consolidated Edison Company of New York, Inc., New York, N. Y.)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Air Conditioning and Refrigeration. By B. H. Jennings and S. R. Lewis. Second edition. International Textbook Company, Scranton, Pa., 1944. 517 pages, illustrated, 9 by 6 inches, fabrikoid, $4.50. (ESL.)

The first edition of this book, published in 1939 as, "Air Conditioning, Principles and Practice," aimed to present the fundamentals of air conditioning so as to provide engineering students and practicing engineers with a sufficient basis for work in this field. This new edition has been thoroughly revised and modernized and the information on refrigeration greatly extended, so that the book also can serve as a text on that subject.

Arc and Acetylene Welding. By H. Kerwin. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 240 pages, illustrated, 8 by 5¼ inches, cloth, $2.50. (ESL.)

This book is designed for beginners or for instructors who understand the technical problems of welding but not its practical aspects. This course presents, step by step, the procedure necessary to make satisfactory acetylene and arc welds, emphasizing proper technique. In addition to basic methods applications to aircraft and pipe welding, cast-iron welding, and alloy welding are treated.

Automatic Control Engineering. By E. S. Smith. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 367 pages, illustrated, 8½ by 5¼ inches, cloth, $4. (ESL.)

This book brings together, for the first time in the English language, a general discussion of processes of control, control mechanisms, and servomechanisms. Its purpose is to provide tools to aid in the solution of problems in automatic regulation wherever they occur. The subject is approached first qualitatively and then is analyzed quantitatively. Appendixes provide a review of basic physics and the mathematics of physical transients.

Down to Earth. By D. Greenhood. Holiday House, New York, N. Y., 1944. 262 pages, illustrated, 11¼ by 8½ inches, cloth, $4. (ESL.)

This book, written for the amateur, provides a general survey of maps and map making. The theories and techniques of mapping are developed in simple language, clearly and explicitly. Directions are given for making maps and for collecting them. The book is illustrated profusely and will interest map makers and users alike.

Engineering Materials Annual 1944. Edited by H. H. Jackson. Paul Elek (publishers) London, W.C.2, England. 108 pages, 8¼ by 5 inches, cloth, 8*s*.6*d*. (ESL.)

This manual gives a concise review of important developments in engineering materials during the year 1943. It includes articles on ferrous and nonferrous metals, plastics of all kinds, ceramic materials, fuels, lubricants, plywood, and adhesives. Each review is accompanied by a bibliography.

Engineering Production Annual 1944. Edited by H. H. Jackson. Paul Elek (publishers) London, W.C.2., England. 102 pages, 8¼ by 5 inches, cloth, 8*s*.6*d*. (ESL.)

This short volume reviews developments during 1943 in machine-shop methods, machine tools, welding, powder metallurgy, hardening, and so forth. Each review is accompanied by a list of references to the articles from which the review was prepared.

Explosions, Their Anatomy and Destructiveness. By C. S. Robinson. McGraw-Hill Book Company, New York, N. Y., and London, England, 1944. 88 pages, illustrated, 8½ by 5 inches, cloth, $1.50. (ESL.)

For the benefit of all those who may have contact with explosives, this small book describes the sequence of events that lead up to an explosion, the phenomena produced, and the effects of these phenomena on the surroundings. A brief study of a large number of notable explosions is included.

Fields and Waves in Modern Radio. By S. Ramo and J. R. Whinnery. John Wiley and Sons, Inc., New York, N. Y.; Chapman

and Hall, London, England, 1944. 502 pages, illustrated, 8½ by 5½ inches, cloth, $5. (ESL.)

This book is concerned with certain aspects of electromagnetic theory in their relations to the problems of modern radio and electronics engineering. The first six chapters discuss the electromagnetics of the lower frequencies and provide an introduction to the treatment of the higher frequencies in succeeding chapters. These later chapters cover the propagation and reflection of electromagnetic waves, characteristics of wave guides and transmission lines, resonant cavities, and radiation.

Grosse Masszahl und Einheit. By M. Landolt. Rascher and Cie Verlag, Zürich, Switzerland, 1943. 85 pages, tables. 8 by 5¼ inches, paper, 5.80 francs. (ESL.)

This small book deals with the methods of handling quantities, such as lengths expressed in meters, output expressed in horsepower, and so forth, in various calculations, as distinguished from calculations using pure numbers only.

Marine Radio Manual. Edited by M. H. Strichartz. Cornell Maritime Press, New York, N. Y., 1944. 518 pages, illustrated, 7½ by 5 inches, fabrikoid, $4. (ESL.)

This manual provides a detailed comprehensive account of the duties of the ship radio officer. The text is clear and readable, and covers the fundamentals and advanced duties. In addition to being a text for the beginner, it will be useful to the commissioned officer for reference.

Metallography of Some Aluminium Alloys. (Association series number RRA 635.) By M. D. Smith. British Nonferrous Metals Research Association, Euston St., London, N.W.1, England, November 1943. 12 pages, illustrated, 9¼ by 6¼ inches, paper, 2*s*. (ESL.)

This brochure describes work on the constitution and metallography of aluminium alloys in common use. Cooling curves were taken, and the structure of the alloys examined in the cast condition and after quenching from various temperatures. There are 28 photomicrographs.

Municipal Index and Atlas. Nineteenth Annual Edition—1944. American City Magazine Corporation, New York, N. Y. 663 pages, illustrated, 10¼ by 7 inches, fabrikoid, $5. (ESL.)

This volume, like preceding issues, is intended as a reference manual for municipal officials. Under such headings as streets and highways, water supply, sewage and garbage collection, lighting and power, public safety, recreation, and business machines, it reviews recent developments in municipal affairs. Manufacturers' data are included.

Ordinary Differential Equations. By E. L. Ince. Dover Publications, New York, N. Y., 1944. 558 pages, illustrated, 9¼ by 5½ inches, fabrikoid, $3.75. (ESL.)

This book originally appeared in 1927 and at once was accepted as a standard work on its subject. It has been out of print for some time, and this edition, costing about one fourth the original price, will be welcomed by mathematicians, engineers, and others.

Physics of the 20th Century. By P. Jordan, translated by E. Oshry. Philosophical Library, New York, N. Y., 1944. 185 pages, 8½ by 5½ inches, cloth, $4. (ESL.)

This book, which appeared in Germany a few years before World War II, aims to give a complete picture of modern physics in broad outline. Attention is concentrated on the underlying ideas that have guided the efforts of physicists from the time of Galileo to the present day.

Plastic Working of Metals and Nonmetallic Materials in Presses. By E. V. Crane. Third edition. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 540 pages, illustrated, 8½ by 5½ inches, fabrikoid, $5. (ESL.)

In this edition the author has expanded his work on sheet-metal working and forging to include powdered metals, synthetic plastic powders, and other materials now worked plastically. The methods used in working these materials are studied and described in considerable detail, and an effort is made to classify the metal-working operations into groups and to establish a working theory for predicting results with various materials.

Results of Publicly Owned Electric Systems. Burns and McDonnell Engineering Company, Consulting Engineers, Kansas City, Mo., 1944. 447 pages, illustrated, 9 by 6¼ inches, paper, $10. (ESL.)

This handbook gives the records for the year 1943-44, of publicly owned electric utilities in 767 American cities. Operating data and rates are given. Other features are a comparison of rates of publicly owned and private systems, accounts of the results of public power developments in the Northwest and in the Tennessee valley and of the work of the Rural Electrification Administration.

SAE Handbook, 1944 Edition. Society of Automotive Engineers, 29 West 39th St., New York, N. Y., 1944. 804 pages, illustrated, 8½ by 5½ inches, fabrikoid, $5. (ESL.)

The 1944 edition gives the officers and committees of the Society and also contains the standards at present adopted by the organization.

Symposium on the Applications of Synthetic Rubbers. American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa. 134 pages, illustrated, 9 by 6 inches, paper, $1.50, cloth, $1.75; to ASTM members, paper, $1, cloth, $1.25. (ESL.)

This pamphlet contains 13 papers presented at the Cincinnati, Ohio, meeting of the Society in March 1944. The purpose was an authoritative presentation of present knowledge of synthetic rubbers which will aid users in the selection of the best material for various purposes. Among the subjects are: the origin and development of synthetic rubbers; their physical testing and properties; processing characteristics; use in making extruded products; tires and inner tubes; belting and hose; cellular products; hard rubber products; uses in wire and cable; footwear; adhesives.

Fundamentals of Telephony. By A. L. Albert. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1943. 374 pages, illustrated, 8½ by 5½ inches, cloth, $3.25. (ESL.)

This is an elementary text on wire telephony only, intended for beginning students and telephone workers rather than for trained engineers.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Four Years' Pioneering in Plastics Education. Plastics Industries Technical Institute, 122 East 42nd Street, New York, N. Y., 16 pages.

Reconversion. By James F. Byrnes. Office of War Mobilization, Washington, D. C., 14 pages.

Facts for Industry, Series 50-3-1. Bureau of Census, Washington 25, D. C., 30 pages.

Bibliography of Industrial Engineering and Management Literature. By Ralph M. Barnes and Norma A. Englert. University of Iowa, Iowa City, 80 pages, $1.50.

Sixteenth Report to Congress on Lend-Lease Operations. United States Government Printing Office, Washington, D. C., 88 pages.

A Suggested Street Lighting Plan Book for Utilities. National Electrical Manufacturers Association, 155 East 44th Street, New York 17, N. Y., 56 pages, $1.

Light Metals and Stainless Steel. Pennsylvania Department of Commerce, State Planning Board, Harrisburg, Pa., 44 pages.

Some Characteristics of Acid Regenerated Carbonaceous Zeolite. By Frank N. Kemmer and Joseph Thompson. The Cochrane Corporation, Philadelphia, Pa., 5 pages, no charge.

Metal Quality. Drop Forging Association, 605 Hanna Building, Cleveland, Ohio, 40 pages.

Low Cost—the Key to Full Postwar Employment. By Albert Ramond. Albert Ramond and Associates, Inc., Chrysler Building, New York 17, N. Y., 15 pages.

Oil Circuit Breaker Bushing Test Practice. By Ernst J. Mommo. Public Service Electric and Gas Company, Maplewood, N. J.

Keeping Air Circuit Breakers in Trim. I-T-E Circuit Breaker Company, 19th and Hamilton Streets, Philadelphia 30, Pa., 8 pages.

Working Principles of Electric Arc Welding. Harnischfeger Corporation, Milwaukee 14, Wis., 68 pages, $1.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Aircraft Storage-Battery Design

JOHN L. RUPP
NONMEMBER AIEE

WITH the present great interest in aircraft, not only because of its wartime importance, but also because of the prominence it will have commercially after the war, as well as in postwar military needs, a careful scrutiny of the vital parts that make up the aircraft is in order. One of these parts is obviously the aircraft storage battery. It is used for engine starting, ignition, lighting, and radio.

The paper points out wherein the aircraft battery requirements differ from battery requirements encountered heretofore. Then step by step each of the important parts that goes to make the unit complete is described, and information is given as to what has been done in design to cause these parts to provide a performance of that part to meet aircraft usage.

Attention is called to certain departures that have occurred from what may be considered sound practice, and reasons are given as to how this occurred.

Suggestions are made as to methods of correcting these departures and of experimental work that is being carried on for further improvement.

In summarizing the data and experience accumulated, a suggested design is offered which should overcome the present deficiencies and meet present requirements.

Requirements

The design of aircraft storage batteries involves two major considerations which differentiate the problem from batteries for ground or marine uses. There is obviously first of all weight, and second a nonspill feature which will permit the battery to function at least for a limited time in any position.

Storage batteries usually are associated in one's mind with great weight, but since they are one of the best-known means for the storage of energy, which immediately can be converted to electrical use, intense effort and attention have been directed toward reducing the weight consistent with required service. The resulting watts per pound of weight of the battery compares favorably with other units on the aircraft.

Paper 44-112, recommended by the AIEE committee on air transportation for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944. Manuscript submitted February 23, 1944; made available for printing May 23, 1944.

JOHN L. RUPP is vice-president, National Battery Company, Depew, N. Y.

Methods for Weight Reduction

The most apparent and fertile field for work on weight reduction has been the reduction of life expectancy of the battery down to a reasonable point for aircraft use. Like a shoe, the wear of which is proportional to the thickness of the sole, the wear in a battery is proportional to the thickness of the plates. Where life expectancy had been considered in periods of from 5 to 15 years, to consider it in from months to a year allowed much latitude for weight reduction.

Grids

The supporting framework for the active material of a lead storage battery consists of grids of antimonial lead. The long-life heavy battery will have grids of heavy section, and the antimonial content usually will be eight per cent. By increasing this content to 12 per cent, the eutectic point for this alloy, and by allowing specific limited amounts of impurities, such as tin, copper, and arsenic to be present, good castings can be made in very light sections and thicknesses. The grid life will be reduced, but not below a period of reasonable service. Figure 1 illustrates the difference in thickness and member sections of a battery grid designed to give 4½ years of life and an aircraft battery grid.

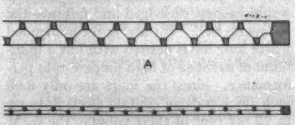


Figure 1

A. A typical positive-grid section designed to give 4½ years of life in reasonable heavy service

B. An aircraft positive-grid section. The lighter section and thickness are obvious

Advantage is taken of the fact that, while the lead peroxide of the positive plate tends to distort its supporting grid by buckling and expanding it, thus requiring a sturdy construction, the sponge lead of the negative does not. The negative grid, since it need only support this sponge lead and act as a conductor, may be constructed of light members with horizontal bars far apart and verticals light in section.

Because aircraft batteries may be charged on a stationary bench in contrast to the vibration they receive in a plane, the practice of including feet on the grids as is done in many other types of service is continued. This permits the two feet of each plate of a given polarity to rest on the same bridges as the rest of the plates of that polarity, while the two feet of the plates of opposite polarity rest on alternate bridges. The sediment that clings to the bridges will in this manner be unable to cause short circuits between plates (see Figure 2).

Active Material

The finished active material of the positive plate is lead peroxide (PbO_2). This

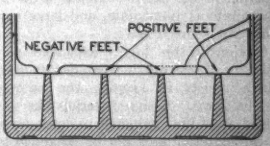


Figure 2. There are four bridges. The feet of the positive plates (two each) rest on alternate bridges. The feet of the negative plates rest on their alternate bridges

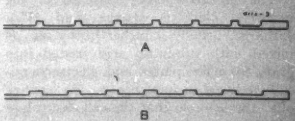


Figure 3

A. The profile of a microporous separator

B. The profile of a wood separator

Since the former has greater mechanical strength, the ribs may be narrower allowing more open space between them and greater acid in contact with the plate

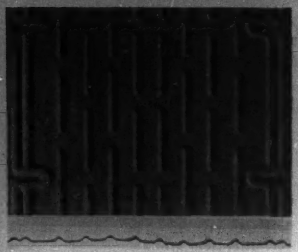


Figure 4. The cross section is constant, decreasing the material used. The ohmic resistance is low because there are no thick sections

is produced by mixing with a solution of sulphuric acid and water an oxide of lead, usually red lead (Pb_3O_4) or litharge (PbO) or both, and further oxidation occurs when this plate serves as an anode in an electrochemical bath using sulphuric acid as an electrolyte. The mixture of oxide and acid solution is made into a heavy paste and applied to the grids with a hand paddle or by a special machine. A wide variation in porosity may be obtained by changing the proportions of red lead and litharge used, the weight of these oxides per unit of volume, and the specific gravity of mixing acid used. Since an aircraft battery is called upon to deliver high currents for short intervals, an open porous peroxide is needed. Therefore, a lightweight red lead usually is selected and mixed with a rather high specific-gravity acid. The resulting large and numerous pores give ready access of the cell electrolyte into the plate. The reaction of the active material with the electrolyte is immediate, and large currents can be delivered.

Obviously this highly expanded peroxide is of less weight than denser ones, which assists in keeping the battery weight down. Active materials like this are of short life compared to dense ones, so the material must not be expanded to a point where it will shed out and fall uselessly into the sediment wells before a reasonable battery life has been obtained.

The finished active material of the negative plate is sponge lead (Pb). Litharge, usually a rather heavy one, is mixed with sulphuric acid pasted into grids to make plates and electrochemically reduced to sponge lead. To "sponge out" the lead, so that the cell electrolyte will have ready access and to further aid in the output of the battery, a small percentage of lamp black and barium sulphate is added. The carbon serves mostly to increase the sponginess but also aids as an electric conductor; the barium sulphate changes the crystalline structure, keeping the crystals small and finely divided. Certain organic materials in small quantities are added to increase the battery output at low temperatures. Among these are wood dust, lignin, hemp, cotton, cork, and humic acid. They are used in quantities of only a fraction of one per cent by weight. Seemingly, they take no part in the reaction, but on discharge will increase the battery output at −20 degrees Fahrenheit to five times that obtainable without them.

Separators

Separators used are microporous rubber or treated wood. Either may be used in conjunction with a glass mat. The mat does not act as a separator but as a retainer of the positive active material. It is applied between the grooved side of the separator and the surface of the positive active material, thus holding mechanically in place material that otherwise would become dislodged and fall into the sediment well. Its use is recommended where long life is desired with but a minimum of sacrifice of high-ampere-rate performance. Since the mats are only 0.03 inch thick and can contain electrolyte up to 90 per cent of their volume, the slight additional internal resistance which they offer is almost offset by the more immediate access they permit of the electrolyte to the positive active material. The use of glass mats may be expected to add 50 per cent to the life of the battery.

Microporous-rubber separators are preferable to wood. They more nearly balance out the life of the separator to the plates than do the wood separators. Their cost is higher than wood, but the increase represents only about five per cent of the cost of the complete battery.

Additional advantages are:

1. The lower ohmic resistance per unit of projected area results in lower internal resistance of the cell and consequently higher cell voltages on discharges.

2. Since they do not require treatment before use, they may be inserted into position between the plates in a dry state.

This permits the battery to be stored dry for an indefinite period without deterioration. The battery can be filled with electrolyte and charged wherever needed with no loss in performance or life, regardless of the storage period.

Batteries insulated with moist wood separators and stored deteriorate seriously after six months of storage.

The wood separator, so far as kind of wood, general profile, and shape, follows that conventionally found in automobile batteries, except that, because of weight and space limitations, it must be made in thinner sections. Preferred wood is cedar, but fir, cypress, and redwood are used. It may be sawed, rotary-cut veneered, or sliced.

To remove natural resins which are harmful to the plates, the wood, after being grooved, is treated in a three per cent solution of caustic. This also serves

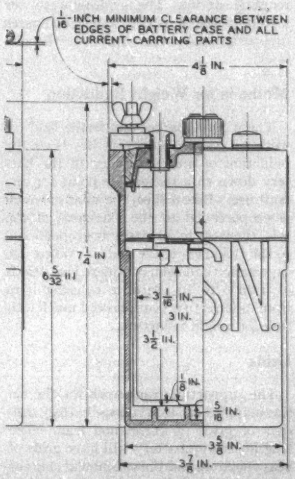


Figure 5. Liberty-motor ignition battery

The space above the electrolyte will hold all of the electrolyte when battery is on its side without submerging vent plug. When upside down, electrolyte will not submerge hole in end of vent tube

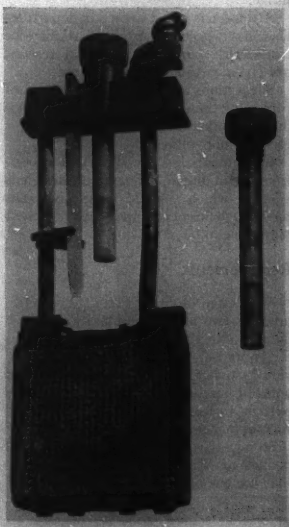


Figure 6. The present German construction is little different from Figure 5. The visual level indicator (rectangular glass plate) is unique

to decrease the ohmic resistance, but after treatment the separator must be kept moist or it will develop a high resistance and become weak mechanically exhibiting splits and cracks.

The usual practice in either microporous rubber or wood is to allow an 0.030-inch back web and a groove 0.040 inch deep. The purpose is to make the separator resistance low and to allow as much electrolyte as possible to come between the plates for ready reaction with the active material. Conventional profile of the separators is shown in Figure 3.

Recent experiments on a microporous separator of a profile as shown in Figure 4 shows promise. Here the cross section through the separator has been kept constant. A 20 per cent decrease in ohmic resistance is achieved. The shape lends itself more readily to the manufacture of synthetic rubber. The volume and weight of material used is lessened by one fifth. As far as tests have progressed results have been good both as to life and discharge. The separator has been produced only on a laboratory basis.

Electrolyte

Sulphuric acid with a specific gravity when the battery is fully charged of 1.285 is used. Permissible impurities in this specific gravity are:

Impurity	Per Cent	Impurity	Per Cent
Iron	0.006	Nitrates	None
Arsenic	0.00005	Ammonia	0.00600
Antimony	0.00050	Chloride	0.01200
Manganese	0.00002	Copper	0.00500

Mechanical Construction

The first requirement for an especially designed lead–acid storage battery for aircraft occurred during World War I with the development of the Liberty motor, where it was desired to supplement the magneto with battery ignition. The battery designed and used was a small eight-volt one capable of delivering three amperes for three hours. Because many of the features found in it are still desirable, it is shown in section in Figure 5.

It will be noted that the nonspill feature was obtained by enlarging the electrolyte expansion chamber sufficiently, so that when the battery was placed on its side the electrolyte that ran from the cell proper was insufficient to rise to the vent plug in the center of the cell. When the battery was inverted the electrolyte was insufficient to rise to the hole in the lower end of the vent tube. Thus at all times the vent remained open for the escape of gas, but the electrolyte could not at any time reach the opening and run out. Since the periods during which the battery was inverted were short, sufficient acid was retained in the plates and separators, so that the reaction could continue and the battery deliver current. The use of glass mats even further aids under these inverted conditions.

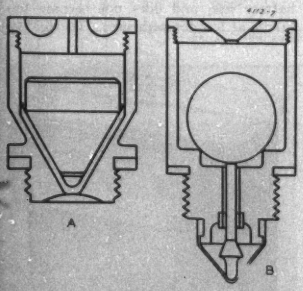


Figure 7

A. The lead weight slides along the inside conical surface of the plug body until it closes the hole in the plug top

B. The lead ball rolls off the valve stem permitting the rubber "spring" at the bottom to close the rubber-seated poppet valve

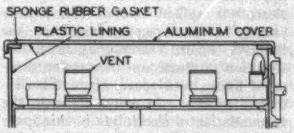


Figure 8. Electrolyte spilled from the vent is confined in the space enclosed by the plastic-lined aluminum container and lid

This space also contains the intercell connectors and terminals, which may become short-circuited if there is much acid

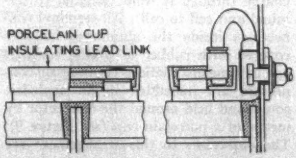


Figure 9. Intercell connector fitted with porcelain cup which is filled with asphaltic compound

The only disadvantages of this type of construction are:

1. The difficulty in obtaining a specific gravity reading, as the normal electrolyte level is well down below the vent plug opening in the cover.

2. The nonspill space required increases the cubical dimensions per ampere-hour as compared with conventional types.

It does not appreciably increase the weight per ampere-hour.

Specific-gravity readings may be taken by placing the battery on its side with vent plug removed, and by using a hydrometer syringe with a curved tube, so that the syringe body is in a vertical position when the tube end is immersed in the electrolyte.

Figure 10. The junction box containing the terminals must of necessity be small, making the application of the cable lugs to the battery terminal studs difficult

It is considered that this construction is still the most effective nonspill one developed.

Figure 6 shows the present German construction. It is interesting to note that they have adhered to this old construction but have added an electrolyte level indicator. The indicator consists simply of a strip of glass extending through the cover down to the normal electrolyte level. In ordinary daylight or with average lighting, the lower end of the glass appears as a greenish-white rectangle upon peering down through its upper end, that is, if the electrolyte is below normal level (the end of the glass strip). When water is added through the vent hole and as the level rises until it touches the lower end of the glass the greenish-white rectangle disappears leaving only darkness. The operator thus knows that the normal level has been reached.

An improvement on the German method has been made by using a rod of methylmethacrylate. By tapering the lower end to a cone and by observing the ensuing dark circle that appears as compared in size with the rod circumference it is possible to judge how far up the cone the level has risen. In this way a level "range" is obtained instead of simply "below normal" or "normal or more."

In passing, comment is made that German lead–acid aircraft batteries compare unfavorably with United States batteries in ampere-hours per pound of weight. This is because of design and not forced substitution of materials. Their principal loss is in their grid construction

For 15 years the desire of plane users has been away from the construction previously described to a battery having only the normal necessary expansion space and the use of vent plugs with check-valve arrangements which, upon rotating the battery, would close before the electrolyte reached them. This does result in a reduction of over-all height, but not a material one, as in incorporating the check-valve arrangement, whatever it may be, additional height must be given to the vent plug.

Figure 7 shows two types that have been used widely. In one case the inverted lead cone slides along the conical surface of the vent-plug body until it comes in contact with the vent top closing the vent hole. This should occur before the electrolyte reaches it. In the other the lead ball rolls off the hard-rubber valve stem allowing the rubber band at the bottom of the plug to force shut the poppet valve mounted on the stem. Even lead is subject to some corrosion by sulphuric acid, making parts stick and become inoperative. Disassembling the plug and cleaning it or discarding it for a new one becomes necessary.

A major objection to the check-valve vent plug is its failure to allow the venting of gas when closed. Some gas is given off from the battery on discharge, and a great deal is given off on charge, the amount being dependent on the amperage of the charging current and the state of charge of the battery. Present generators have extremely high amperage output, and it is not expected that the comparatively small batteries used can absorb it. Voltage regulators are used to control the input to the battery. Should these regulators become inoperative even for a short time, the gas evolved by the battery, even though it is in a partially charged condition, is enormous, and the vent plug has difficulty to relieve it when in an open position. If closed, a pressure is built up quickly which can force the cell cover out of the container, break the seal, and allow complete spillage of the acid.

To collect electrolyte spillage from nonfunctioning vent plugs, the aluminum boxes and covers in which the batteries are encased to provide radio shielding are lined with soft rubber or an acid-proof plastic. A rubber gasket is applied between the aluminum case and cover, so that, when the hold-downs are drawn up, a seal is obtained which will hold any electrolyte spilled out of the battery proper in the open space above the battery. Figure 8 shows the general construction of aluminum box, cover, acid-proof lining, and space where the electrolyte collects. In many instances the accumulation of electrolyte in this space has been so great that drainage tubes have been provided in the aluminum container, so that the spillage can be collected in a separate container away from the battery.

The accumulation of acid on top of the battery may cause the battery to discharge through it from terminal to terminal and cell to cell. All terminal connections inside the aluminum box are covered with rubber or plastic coatings and in some installations the intercell connectors are imbedded in an asphaltic compound held around the connector by means of a porcelain cup (see Figure 9). The objections to this arrangement are the difficulty of removing a connector to open up a cell for examination or repair and the undesirable heat insulation of the connector. Because of the need for light weight, the cross section of the lead connectors is kept small.

Outside Terminal Connections

The present practice is to bring the battery terminals through the aluminum box by means of lead-coated brass studs encased in acid-proof nonconducting bushings drawn down with nuts. The cable ends of the plane harness to the power source and battery load are supplied with terminal lugs and are attached to the protruding studs and held with wing nuts. This outside assembly is encased in an aluminum junction box for radio shielding. The cables enter the box through knockout holes to which the cable shield is attached (see Figure 10).

While this is an effective connection, confined space often makes it awkward as the lid of the junction box must be removed to reach the wing nuts. Other interfering equipment on the plane may make these wing nuts difficult to reach.

Consideration is being given to quick-acting positive connections, such as is shown in Figure 11. It is believed that there will be no weight increase, and that a better and more effective connector will result.

Cell or Battery Container

Hard rubber of good quality having an elongation of six per cent and a tensile strength of 5,000 pounds per square inch has been used for aircraft containers since their inception. It is sufficiently nonacid absorbent to outlast the battery plates. It is reasonably light in weight, does not soften until aforementioned temperatures encountered in satisfactory battery use, and does not become too brittle at low temperatures. Its rigidity

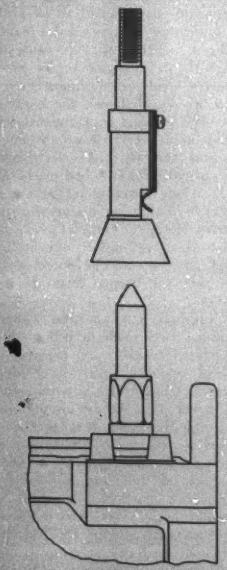


Figure 11. This push-on terminal holds promise

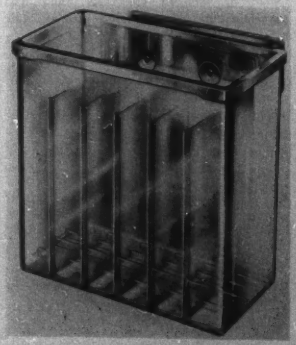


Figure 12. Instead of separate aluminum box, acidproof lining, and internal hard-rubber monobloc, the unit is in one polystyrene piece

Figure 13. The polystyrene assembly plated with 0.001 inch of lead for radio shielding

is high enough so as not to distort when subjected to hold-down pressures sufficient to hold the battery in place. Could hard rubber of the quality described continue to be available, it is doubtful whether any serious search would be made for a substitute, but the scarcity of natural crude rubber has necessitated dropping the elongation to three per cent and the tensile strength to 4,000 pounds. This has brought about some weight increase.

Much research has been done to find a substitute. Cellulose nitrate has the necessary characteristics for a battery container and long has been used as such. It can be fabricated easily without large tool and mold costs and is plentiful, but it is highly inflammable and hazardous to work with during manufacture and use.

Hydrolized wood has been given attention and is still being investigated.

The most promising material is the plastic polystyrene. It has all of the desirable features of hard rubber plus the fact that it may be used in thinner sections, resulting in a sizable saving in weight. The present problem is not the material itself nor any lack of physical or chemical requirements, but rather the problem of molding.

Polystyrene is a thermoplastic and injection molding of battery cases in sizes smaller than are necessary in aircraft and has been quite successful. Many thousands are being built or are already in use. They are light in weight, transparent (so that the physical condition of the battery may be observed); covers are cemented to the container and become an integral part of it (making sealing leaks impossible), are cleaned easily, thus avoiding external short circuiting.

Aircraft batteries of this material have been built wherein the polystyrene replaced the aluminum box, acid-proof lining, and hard-rubber cell container in one piece. The resultant weight saving was several pounds on a 12-volt 34-ampere-hour battery. All metal in the box construction that might be subject to acid corrosion was eliminated.

The weakness in this polystyrene unit assembly came from the fact that, at the time the work was done, no press large enough to make the box with one injection was available, and from four to six injections had to be made to fill the mold. Strains in the unit resulted, and fractures occurred at low temperatures during vibration. It is believed that, when sufficiently large presses are available to handle a unit of this size with one injection, a conversion to this material and construction may follow. This will be governed also by the supply of available natural rubber or development in the technique of handling synthetic rubbers. Figure 12 shows the unit polystyrene assembly.

The main purpose of the aluminum box in present design is for radio shielding, although as has been pointed out, since it has been provided with an acid-proof lining, its upper portion together with its lid or cover acts as a container for spilled electrolyte. In the case of the polystyrene unit assembly the radio shielding was accomplished by electroplating the outer surface of container and cover with a coating of cadmium. Later lead was used, being preferable as it is acid-resistant and painting of the box was unnecessary. Both of these metals adhered excellently, and rough treatment such as blows with a blunt instrument and scratching did not loosen them nor cause them to peel. The coatings used were from 0.001 to 0.0015 inch thick and added but 2.5 ounces to the container weight; whereas, for the same size battery the aluminum box weighs 3.25 pounds.

Figure 13 shows the polystyrene unit assembly plated with 0.001 inch of lead.

Suggested Design

Many of the objections to present-day aircraft designs are the result of rapidly changing conditions, causing the adoption of one expedient after another. To overcome one weakness some stopgap was used, which in turn had its own drawbacks, and additional adaptations had to be made to correct it.

As a postwar design, or as a war design if materials and tools become available, the following is suggested:

1. Revert to the old nonspill method using the large electrolyte expansion space and the tube vent plug. It will not spill, and gas is vented during inversion.
2. Provide a rod-type visual acid-indicating device.
3. Use a simple positive quick-acting push-on terminal connection.
4. Manufacture the container complete of hard rubber (if available) or polystyrene plastic. If the latter is used, since it is transparent, the visual indicating device may be eliminated, unless radio shielding is necessary.
5. Definitely determine whether radio-battery shielding is necessary. There has been some doubt on this point.
6. If necessary accomplish the shielding by electroplating.
7. Also, if necessary, provide a simple hard-rubber or plastic lid electroplated and clamped to the battery top.

A design such as this will be light in weight, actually nonspill, easy to install and remove, and readily connected to the plane wiring. Figure 14 is a suggested general design.

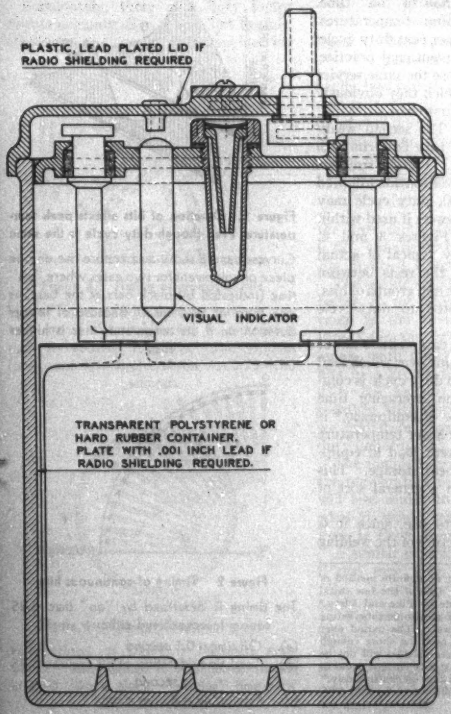

PLASTIC, LEAD PLATED LID IF RADIO SHIELDING REQUIRED
VISUAL INDICATOR
TRANSPARENT POLYSTYRENE OR HARD RUBBER CONTAINER. PLATE WITH .001 INCH LEAD IF RADIO SHIELDING REQUIRED.

Figure 14. This design suggests plastic container, plating for radio shielding, tube-type vent for nonspill, push-on terminals, and visual indicating device

Rating of Electric Equipment Under Intermittent Load

MYRON ZUCKER
MEMBER AIEE

Synopsis: Resistance welding furnishes a clear-cut case of intermittent load. The more elaborate and expensive equipment that marks the trend in welding away from a blacksmith's art to a carefully controlled science warrants increased care in design. This paper explores one aspect of this design: the thermal limits to the periodic load that can be carried. In this case the application is to resistance-welding problems, and illustrative material is drawn from a type of interleaved flexible welding cable that has seen seven years' service in industry. The principles, however, apply to all types of welding: in fact, they extend to many fields in which the problem is to find the reaction to an intermittent force—such as electrical or mechanical transients.

Analysis of Ratings Under Intermittent Load

Shortcomings of Duty Cycle

WHEN electric equipment is subjected to intermittent load, as in spot-, flash-, projection-, or gun-welding, it is customary to rate it according to the duty cycle[1,2] under which it is to be used. This is good practice as long as we take duty cycle for what it really is: the proportion of *time* that the equipment is heated—or current "on" time divided by total time. But we may get into trouble by extending this definition to say that *temperature rise* is proportional to duty cycle—as is commonly done in rating welding equipment for intermittent load.

In the past, uncertainty of design has called for such large safety factors in welding equipment that the errors inherent in using duty cycle as a load multiplier were unimportant. The advance in the art justifies a review of this situation. Such a review shows that for periodic loads there is a more accurate—and, in many cases, an easier-to-use—method for calculating maximum temperature of the machine.

There are two indictments against duty cycle and its associated averaging time:

1. It does not properly account for the individual heating and cooling curves.

2. It does not properly account for the grouping of impulses.

These two errors work in opposite directions. They frequently compensate each other to a great degree, giving a passable result—which may be the reason why duty cycle has worked as well as it has.

Before undertaking the mathematical analysis of heating under intermittent load, let us get a graphical picture of the errors in duty cycle by studying the temperature reached when load is periodically applied and removed.

Individual Hit Cycles. Figure 1 shows two temperature–time curves for two single hit cycles of different durations but the same *proportion* of "on" time. Contrast the maximum temperatures. Both cases have 33.3 per cent duty cycle, and, according to conventional practice, are considered to impose the same service on the equipment—which they obviously do not. That is the first error.

Groups of Hits. The second weakness concerns series of time patterns such as Figures 2, 3, and 4. For the simplest case (Figure 2, an on–off routine followed for an indefinite time), duty cycle may give nearly correct answers if used within proper limits. But Figures 3 and 4, which are more nearly typical of actual operation because of the rests between limited numbers of hits and groups of hits, is not so well adapted to duty-cycle calculation.

The trouble in this case centers about maximum averaging time over which load is to be averaged when duty cycle is computed. The maximum averaging time assigned to each piece of equipment* is intended to reflect the lower temperature found under intermittent load in equipment having greater heat storage. This intention is correct in a general sort of way.

But it is a chore to use, since it is necessary to draw a picture of the welding operation[2] and slide a maximum averaging time along the time axis to find the part of the picture that includes the most "on" time within the maximum averaging time under consideration.

This limitation on averaging time not only is cumbersome, but gives inconsistent results. It is natural to expect that, as averaging time increases, duty cycle should decrease continuously. But it does no such thing!

Figure 5 illustrates how duty cycle violates the preceding expectation for the pattern of Figure 3 averaged over a wide range of averaging times. The values of duty cycle reach a minimum at multiples of six seconds, stepping up erratically after each multiple, preparatory to a swoop down to the next. An interesting picture, but an absurd standard by which to rate expensive equipment.

Summary. We have, therefore, grounds for questioning the whole duty-cycle procedure. In fact, we will see later that:

1. Duty cycle may be inaccurate by large percentages even in the simplest cases, because:

(a). It does not account for the characteristics of heating.

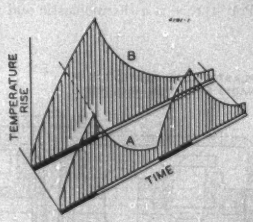


Figure 1. Duration of hits affects peak temperature, even though duty cycle is the same

Curves *A* and *B* show temperature rise on one piece of equipment for two cases where "on" time (indicated by black bars at the base) is one third of total time. Because of longer duration on *B*, its temperature rise is higher than *A*

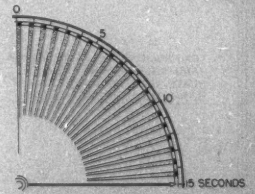


Figure 2 Timing of continuous hits

The timing is described by "on" time 0.25 second, and either:

(a). Off time = 0.5 second
(b). Total time (duration of hit cycle) = 0.75 second
(c). Rate of hits = 80 per minute

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* There seems to have been no definite method of specifying averaging time. One of the few statements in this regard is made by Pike and Ulrey,[1] in discussing the portion of electronic-tube rating that depends on temperature: "The period over which current is averaged must be short enough that the highest temperatures reached will not be in excess of that obtained if steady current equal to the average current rating is kept on continuously." This really requires a different averaging time with each load pattern.

(*b*). Its basic mathematical assumptions are correct only in certain cases.

2. Duty cycle and its associated averaging time are meaningless, inasmuch as they do not properly account for grouping and series of groups of impulses.

In addition, the duty cycle, even in cases where its poor assumptions are acceptable, can be justified only on the basis of maximum temperatures reached—rather than any weighted average such as has been found necessary in rating other equipment.[4] At the present state of knowledge, this point is only academic in welding problems.

Besides these scientific objections, there are some practical ones: cumbersomeness of application; conflict between this use of the term, "duty cycle," and the AIEE definition as applied to circuit breakers; as well as confusion in terminology between duty cycle and heating cycles consisting of so many (60th-of-a-second) cycles on and off. In an effort to clarify the situation, terms such as "per cent duty"[2] have been used. A change in nomenclature, however, is not enough: the procedure requires complete overhauling.

Duty Factor: Its Use and Meaning

Fortunately, there is a duty factor that is not only easy to use, but flexible, consistent, and correct within engineering limits. This duty factor is the product of a hit factor and a group factor. The partial factors are found from some simple charts, the use and derivation of which will be shown.

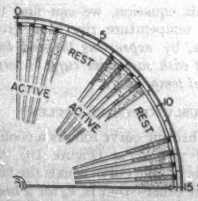


Figure 3. Timing of groups of hits

Hits of Figure 2, with three-second rest after each group of four hits: that is, one group each six seconds. "Active" time includes four complete hit cycles, that is, $4 \times 0.75 = 3.0$ seconds

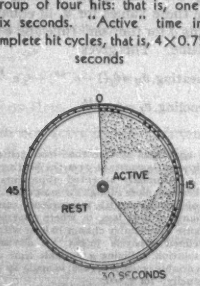


Figure 4. Timing of series of groups

Four groups of Figure 3 repeated every minute. This pattern is duplicated, starting at $t = 0$, like a clock. "Active" time $= 4 \times 6.0 = 24$ seconds

Working Charts

In computing duty factor, the first step is to find the hit duty factor F_h, as though hits were being repeated continuously. This value may be found from either Figure 6 or Figure 7, depending on whether the problem is set up in terms of rest time or of total time or welds per minute. Suppose, for instance, that hits have 0.25 second "on" time and 0.75 second total time (that is, they are made at the rate of 80 per minute). Figure 7A shows that

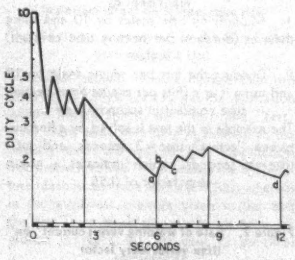


Figure 5. Duty cycle affected erratically by maximum averaging time

For the load pattern of Figure 3, conventional duty cycle sometimes shows big changes (*a* to *b*) for small difference in averaging time used in computation; other cases (*a* to *d*) show no change for large difference in averaging time.

Duty factor avoids this inconsistency

the duty factor for this combination is 0.33: the answer to the case of Figure 2. For Figure 3, a second step is taken.

The second step is to find a group duty factor F_g by taking the *active time* as equal to the *number of hits per group* times *duration* of hit cycle. For example, with four of the aforementioned hits in a group, the active time is $4 \times 0.75 = 3.0$ seconds. Using this value, together with total time $= 6.0$ seconds; we find from Figure 7B that the group duty factor is 0.55.

The complete duty factor that measures the temperature to which the equipment will rise under this load, compared to what it would reach under continuous load, is $F = F_h F_g = 0.33 \times 0.55 = 0.182$.

A similar computation would be made if rest time were used instead of total time. That is, for the same pattern:

1. For hits, we have "on" time $= 0.25$ second, rest time $= 0.5$ second. From Figure 6A, we find $F_h = 0.33$.

2. For groups, "active" time $= 3.0$ seconds, rest time $= 3.0$ seconds. From Figure 6B, we find $F_g = 0.55$.

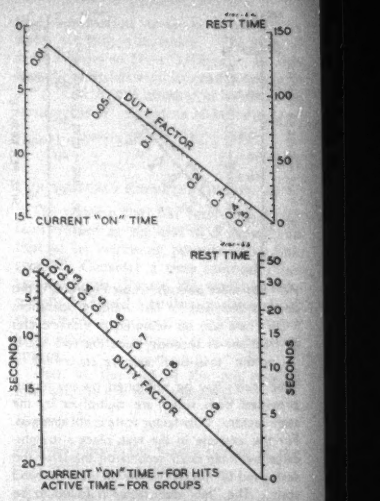


Figure 6. Rest time versus current "on" time versus duty factor, showing fraction of continuous-load temperature rise reached when intermittent load is applied

A. *For short periods.* In welding, this chart usually will be used for single hits, or for a group of hits in pulsation welding

Time scales may be multiplied by any factor provided *both* scales are multiplied. Duty-cycle scale is not changed

For the example given in the text, a straightedge is placed between current "on" $= 2.5$ (that is, 0.25 times a scale multiplier of 10) and rest time $= 5.0$ (that is, 0.5×10). Straightedge then intersects duty-cycle scale at 0.33, which equals Fh

This chart may be used directly for equipment having other heating time constants, if periods do not exceed ten per cent of the heating time constant of the equipment involved

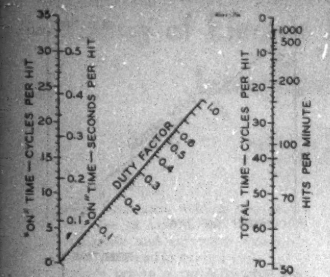
B. *For long periods.* This chart is adapted to groups of hits when there is a rest while changing from weld to weld; or to series of groups when there is a long rest while work is being changed

This chart is designed specifically for interleaved kickless cable, heating time constant $=$ 10 seconds. For other equipment, multiply time scales on chart by 10, and use them as (seconds duration / time constant in seconds) scales

The group duty factor for the example in the text is obtained by placing straightedge between three seconds on the "active" time scale and three seconds on the rest time scale. The straightedge crosses duty-factor scale at 0.55

As before, complete duty factor is $0.33 \times 0.55 = 0.182$.

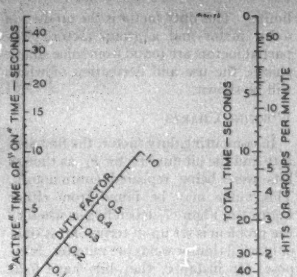
These results are for a light-duty kickless water-cooled welding cable, since the charts are designed for equipment having



A. For short periods. Like Figure 6A, this chart is designed for fast welding operation. "On" time may be measured as either cycles or fractions of seconds, since the two scales on the "total-time" axis are equivalent

Time scales may be multiplied by any factor, provided both scales are multiplied by the same factor. Duty-factor scale is not changed. For the example in the text, place a straightedge between 0.25 second on the left-hand scale, and 80 hits per minute on the right-hand scale. The "hit" duty factor is found to be 0.33, where straightedge intersects the diagonal scale

This chart, like Figure 6A, may be used for any heating time constant, if period does not exceed ten per cent of the time constant of the equipment involved



B. For long periods. This chart serves the same purpose as Figure 6B. It is also designed for kickless cable and is adapted to other equipment by

1. Multiplying time scales by 10 and using them as (duration per heating time constant) scales
2. Dividing the hits per minute scale by 10 and using it as a (hits per minute *times* heating time constant in seconds) scale

The example in the text is solved by a line between "active" time = 3 seconds, and total time = 6 seconds, which indicates a group duty factor of 0.55

Figure 7. Rate of welding versus current "on" time versus duty factor

a time constant of ten seconds which these cables normally have. For other equipment the same charts may be used by changing the time scales as instructed on the charts.

This procedure would be carried one step further if there were series of groups, as in Figure 4. For instance, if after four groups there were an interval of 36 seconds, series multiplier F_s would be obtained in a manner similar to the computation for group factor. In this case, $F_s = 0.84$, making the over-all duty factor $F = F_h F_g F_s = 0.182 \times 0.84 = 0.153$.

These answers may be compared with Figure 5. In this case the duty factor is near the lowest values of "duty cycle"; but this is not a generality—for in many cases the correct duty factor will exceed the duty cycle by a wide margin.

Meaning

The components of duty factor are measures of the temperature that would be attained if the corresponding cycle were to continue indefinitely. The effect of different degrees of continuity is illustrated in Figure 8. If a given load were supplied continuously, temperature rise eventually would be θ_f; if divided into hits, the rise would be only $F_h\theta_f$. (Illustration is for pattern of Figure 2 applied to equipment having such thermal relationships that under continuous load it takes one second for the temperature rise to reach one-half the ultimate value; the rate of rise for this load on ten-second equipment is too slow to permit picturing in space available.) But if, instead of being repeated continuously, hits are broken into groups, the group duty factor tells that only $F_h F_g \theta_f$ would be attained. Further, if there is a rest period between series of groups (Figure 4), we find that the temperature rises only to the fraction F_s of $F_h F_g \theta_f$. With this clue many combinations of periodic on–off patterns can be calculated.

Duty Factor: Derivation

Basic Equations

Finding duty factor for any combination of on–off cycles, really means to derive the maximum temperature under those circumstances.

To do this, we start with the basic exponential equation for temperature change in a single transient. The divergence of this equation from actual heating and cooling curves has been aired thoroughly in AIEE meetings[5] and elsewhere,[6,7,8] but still it is the only practical starting point. In fact, so many kinds of equipment do follow nearly exponential rules that perfectly satisfactory calculations can be made in many cases.

The expressions that have been used in studying the heating of power transformers and other apparatus under heavy load[4] are:

For heating, starting from zero temperature rise, $\theta = \theta_f(1 - e^{-kt})$ (1)

Table I. Dynamic-Equilibrium Temperature Rises

21,000 Amperes on Light-Duty Cable for One-Sixth Second

Hits Per Minute	Maximum Temperature Rise (Degrees Centigrade) By Test	Calculated by Duty Factor	Calculated by Duty Cycle
3	10.0	10.7	6.3
6	17.1	16.8	12.7

For cooling $\theta = \theta_o e^{-kt}$ (2)

where

θ_f = *final* temperature expected from the constant heat input
θ_o = *initial* temperature at $t = 0$
θ = temperature at any time t
$k = 0.693/T$

T = time required to produce half the ultimate temperature rise when load is applied continuously. It is called the "binary heating time constant."[4] The 0.693 is simply inserted to make equations 1 and 2 have the right values at the right times.

For the present analysis, since heating curves seldom start at zero rise, we will use a more general expression* that covers both heating and cooling from any temperature (see Figure 9):

$$\theta = \theta_f(1 - e^{-kt}) + \theta_o e^{-kt} \quad (3)$$

With this equation, we can find the maximum temperature rise in a given duty cycle, by *expressing the end temperature of each successive curve in terms of its initial temperature.*

Continuously Repeated Cycles

When a heating curve follows a cooling curve and vice versa (Figure 10), the initial value of each curve equals the final value of the other—that is, θ_o for a heating curve is θ_L, and θ_o for cooling is θ_H. Therefore, to find the temperatures at the end of the heating and cooling curves, we use these values for θ_o in equation 3, inserting a for the "on" time and b for the "off" time. This gives

After heating, $\theta_H = \theta_f(1 - e^{-ka}) + \theta_L e^{-ka}$ (4)

After cooling, $\theta_L = \theta_H e^{-kb}$ (5)

* These equations assume that heat generated in the equipment is constant over the heating regime. This is a commonly accepted approximation for electric heating, close enough for most cases. When change of resistance with temperature causes material change in heat loss, or where electrical transients cause appreciable change in heat with time, a more refined analysis might be advisable. A partial solution, utilising a variable time constant for the variable-resistance case, is made by Cooney[4] and Kennelly,[9] for $\theta_o = 0$.

Another assumption—common to all applications of the simple exponential equation—is that heat dissipated from the equipment is proportional to temperature rise and that the body is isothermal. Otherwise, the analysis is too complicated for engineering use.[11]

Equation 3 has been developed in many forms. See, for example, reference 10.

To simplify the mathematical development and get usable working charts, we will express temperature rises as fractions of θ_f. Let $\theta_n/\theta_f=H$, and $\theta_L/\theta_f=L$. Then equations 4 and 5 become

$$H=1-e^{-ka}+Le^{-kb}=1-e^{-ka(1-L)} \quad (6)$$

$$L=He^{-kb} \quad (7)$$

We are now ready to consider the rise and fall of temperature as load is applied and removed periodically. If we keep the identity of each cycle (Figure 11), the initial temperature for the nth repetition of the heating curve is the final temperature for the previous cooling curve, L_{n-1}; the initial value for that $(n-1)$st cooling curve is the high point on the $(n-1)$st heating curve, H_{n-1}. Thus,

$$H_n=1-e^{-ka}+L_{n-1}e^{-ka} \quad (8)$$

$$L_{n-1}=H_{n-1}e^{-kb} \quad (9)$$

Then by combining equations 8 and 9, we find H_n, the peak of one cycle, in terms of H_{n-1}, the peak of the preceding cycle:

$$H_n=1-e^{-ka}+H_{n-1}e^{-ka}e^{-kb} \quad (10)$$

Equilibrium—if that is the proper word to use when there is a constant variation over a repeated pattern—is reached when successive values of H and L are equal: that is, when we can drop the subscripts. Then, solving equation 10 for H,

$$H=\frac{1-e^{-ka}}{1-e^{-ka}e^{-kb}} \quad (11)$$

and

$$L=\frac{1-e^{-ka}}{e^{kb}-e^{-ka}} \quad (12)$$

H is thus the duty factor F_h, for continuously repeated hits, in terms of on and off time. To express this in terms of on and total times, we make the common (though debatable) assumption that k is the same for cooling and heating. Then

$$e^{-ka}e^{-kb}=e^{-k(a+b)}=e^{-kc}$$

and equation 11 becomes

$$F_h=\frac{1-e^{-ka}}{1-e^{-kc}} \quad (12a)^*$$

GROUP OF HITS

Let us now solve for the high temperatures, H, within a single group. (We omit low temperatures, because the high temperatures are generally used as a measure of the capacity of equipment.

* If instead of on-off cycle, there is a high-low load cycle,

$$H=\frac{1-e^{-ka}+Pe^{-ka}(1-e^{-kb})}{1-e^{-ka}e^{-kb}}$$

$$=\frac{1-Pe^{-ka}-(1-P)e^{-ka}}{1-e^{-kc}}$$

$$=\frac{1-e^{-ka}+P(e^{-ka}-e^{-kc})}{1-e^{-kc}}$$

where P is the ultimate temperature rise if the light load were applied continuously, divided by θ_f.

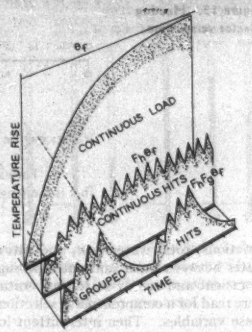


Figure 8. Cutting welds into groups has important effect on temperature rise

The difference is measured by the duty factors derived in the text

The effect actually is more marked than this drawing indicates, since to get the illustration within limited space, the "on" and "rest" times were made very long in relation to the heating time constant of the hypothetical equipment involved. This makes the temperature reach its maximum after a few hits, whereas in the numerical example given in the text the rise is so much slower that it takes six groups to reach 90 per cent of the final temperature

If at any time it becomes advisable to specify an effective temperature involving maximum and minimum values and their relative durations, the treatment should be extended to include this effect.) We will find H_n (Figure 11) by solving for each cycle in succession, starting with equation 8 to get the first cycle in terms of an arbitrary L_0, then using the relation of equation 10, with kc substituted for $k(a+b)$.

For the first hit,

$$H_1=1-e^{-ka}+e^{-ka}L_0 \quad (13)$$

For hit 2, from equation 10 and 13,

$$H_2=1-e^{-ka}+e^{-kc}(1-e^{-ka}+e^{-ka}L_0)$$
$$=(1-e^{-ka})(1+e^{-kc})+e^{-k(a+c)}L_0 \quad (14)$$

For hit 3, from equations 10 and 14,

$$H_3=1-e^{-ka}+e^{-kc}[(1-e^{-ka})(1+e^{-kc})+e^{-k(a+c)}L_0]$$
$$=(1-e^{-ka})[1+e^{-kc}(1+e^{-kc})]+e^{-k(a+2c)}L_0$$
$$=(1-e^{-ka})(1+e^{-kc}+e^{-2kc})+e^{-k(a+2c)}L_0 \quad (15)$$

By continuing this process and comparing equations 13–15 and their successors, we can write the general expression

$$H_n=(1-e^{-ka})\sum_{m=0}^{n-1}e^{-mkc}+L_0e^{-k[a+(n-1)c]} \quad (16)$$

This can be reduced to a more usable form by letting $a+(n-1)c=d$ (see Figure 11), and by taking advantage of the fact that summation term is a geometric series starting with unity. The sum of such a series is $(1-r^N)/(1-r)$. In this case the ratio between successive terms, is e^{-kc}; and N, the number of terms to be summed, is n. Equation 16 becomes

$$H_n=(1-e^{-ka})(1-e^{-knc})/(1-e^{-kc})+L_0e^{-kd} \quad (17)$$

CONTINUOUSLY REPEATED GROUPS

The relation that has been derived for temperature at the end of a group and that at its beginning permits us to link groups. Consider a time interval f between groups (Figure 12), and use subscripts d and $d+1$ to denote the ends of the last hit in respective groups, with g and $g+1$ marking the end of rests between groups.

Then at the end of the gth cooling interval, the low temperature is

$$L_g=H_de^{-kf} \quad (18)$$

whereas during the active period of the next group, from equation 17,

$$H_{d+1}=(1-e^{-ka})(1-e^{-nkc})/(1-e^{-kc})+L_ge^{-kd} \quad (19)$$

If we substitute equation 18 into equation 19,

$$H_{d+1}=(1-e^{-ka})(1-e^{-nkc})/(1-e^{-kc})+H_de^{-kd}e^{-kf} \quad (20)$$

Dynamic equilibrium comes between groups when $H_d=H_{d+1}$. Since this value is the ratio of *maximum temperature*

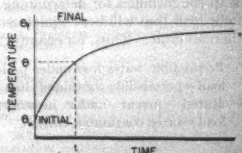


Figure 9. Exponential heating or cooling curve

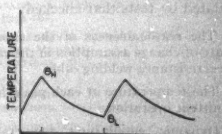


Figure 10. Hit cycle

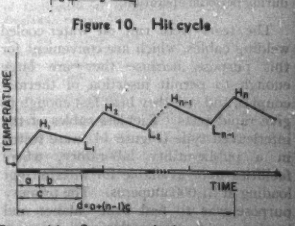


Figure 11. Successive high temperatures in groups of hits

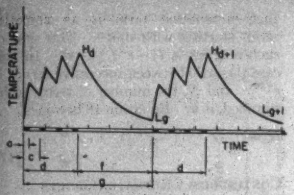


Figure 12. High and low temperatures in successive groups

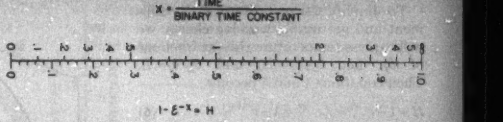


Figure 13. Heating factor versus time

Values may be taken from this alignment chart, for solving equations 20 or 21

For values of x lower than 0.1, $1-e^{-x}=0.693x$

That is the range in which "duty cycle" is accurate for continuous hits

rise under intermittent load to temperature rise under continuous load, we may call it F, the *duty factor*. We find this by solving equation 20, and noting from Figure 11 that $d+f=g$:

$$F=\frac{(1-e^{-kg})(1-e^{-knc})}{(1-e^{-kc})(1-e^{-kg})}=F_hF_g \qquad (21)$$

Thus we have the complete duty factor. In computation, it may be thought of as having either two factors or four. If we use two, as was done in preparing the charts of Figures 6 and 7, the first terms in numerator and denominator combine to give F_h the hit duty factor; the second terms give F_g the group duty factor. Or the four values in parentheses may be taken from Figure 13 (or, for greater accuracy, from a modern table of exponential functions) and combined to find F.

This duty factor takes the place of duty cycle in the formulas for determining the periodic load that will heat equipment to its thermal limit. Thus, for example:

F· Permissible watts loss under periodic load = permissible continuous loss

$\sqrt{F}$· Rated current under intermittent load = rated continuous current

Tests on Kickless Welding Cable

The duty-factor theory has been substantiated by tests that checked:

(*a*). The reasonableness of the exponential-rate-of-change assumption in the case of kickless resistance-welding cable.

(*b*). The temperature at each peak during intermittent operation.

(*c*). Dynamic equilibrium temperatures during periodic operation.

The tests were run on water-cooled welding cables, which are convenient for this purpose because they are large enough to permit insertion of thermocouples, and still they heat fast enough to give rapid tests. Kickless cables of the interleaved type (Figure 14) were tested in a public-utility laboratory, where facilities were available for intermittent loading at 21,000 amperes. The primary purpose was to find heat balance and local temperatures under various combinations of current, cable shape and constrictions, total water flow, and ratio of water between inner and outer passages. Transient and steady-state temperatures were read for a comprehensive selection of these variables. Then intermittent load was applied, several cases having long enough period to permit temperatures to be read after each hit (probably within two degrees centigrade). From these runs data were obtained for the checks previously listed.

Tests for Exponential Rate of Change

Figure 15 shows temperature–time curves for continuous load tests, with three different rates of water flow through light-duty cables. (Similar curves were obtained for heavy-duty cables, but are not needed for this discussion.) The ordinate is really logarithm of (100 per cent temperature change), but is graduated directly in terms of per cent change.

The fact that the tests produced these straight lines gives a sound basis for the use of the exponential expression in the section, "Duty Factor: Its Use and Meaning."

The binary heating time constant is read from each curve: it is the time at which the line crosses the 50 per cent temperature value. Although further tests may refine the time constants, it should be remembered that they do not radically affect temperatures under periodic load. That is, a ten per cent difference in time constant means at most a two or three per cent change in duty factor.

The data for Figure 15 were chosen because of their connection with the inter-

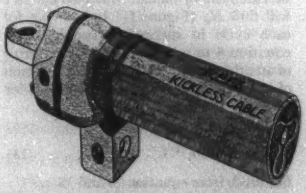


Figure 14. Light-duty Rees kickless cable upon which tests were run

The six component cables may be seen at the cut end. The three within the rubber separator are paralleled at the terminal cap, whereas the three outside the separator are paralleled in the base of the terminal

A stream of water is directed down each cable, in such volume as to equalize the temperature between inner and outer cables. Temperature difference between wire and water is minimized by small sections of copper. Continual spiraling of cables assures water cooling near all points of contact between wire and rubber

Thermocouples were placed in cables and at several points in terminals at water-outlet end of test cable. Temperatures given in other illustrations are hot-spot values

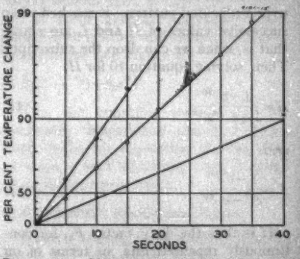


Figure 15. Heating curves for light-duty kickless cable

Each line represents a different rate of water flow through the cable

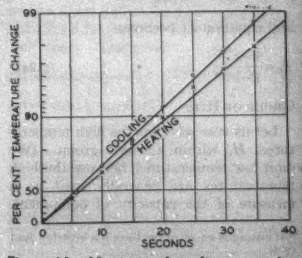


Figure 16. Heating and cooling curves for same water flow

For very accurate computations of duty factor, the difference between heating and cooling time constants may be recognized. In such a case, Figure 6 is more readily used than is Figure 7

mittent load tests, but they are representative of most results. Certain other data were not so accommodating, however, and there is some indication of curvature in the early parts of many tests. More work needs to be done on this matter, if only to determine accurate time constants for various conditions.

A point that may be important is the difference between heating time constants for heating and for cooling. In Figure 16, companion heating and cooling curves are shown. There is a noticeable difference, which seems to be consistent in all tests: cooling time constant is some 20–40 per cent less than heating This may be caused by a combination of

1. Variable losses in the cable due to increasing resistance as the wires heat.

2. The effect of difference between water temperature and copper temperature.

3. The transfer of heat along the cable as the water travels through it.

Strictly, this means that the cooling curves in Figures 8–12 should drop 20–40 per cent faster than they do.

For the present, however, this may be neglected, and the *heating* time constant may be used for both heating and cooling.

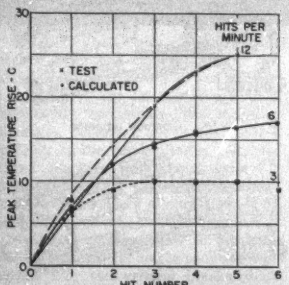


Figure 17. Test versus calculated hot-spot temperatures on light-duty Rees 267,000-circular-mil cable carrying 21,000 amperes for one-sixth second, at rates indicated on chart

Then ratings obtained for a given duty cycle will be conservative, since the calculation will not take account of the faster rate of cooling.

Peak Temperatures at Start of Periodic Heating

In one set of tests on a light-duty cable, hits of 21,000 amperes $^1/_6$-second duration were applied at the rate of 3, 6, and 12 per minute. In each case the temperature rose and fell according to the general pattern of Figure 11: and the high temperatures after each hit should follow equation 17. Test and calculated temperatures are compared in Figure 17.

Similar results were obtained when the

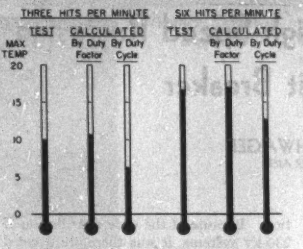


Figure 18. Comparison of test and calculated temperatures on kickless cable carrying 21,000 amperes, current "on" time one-sixth second, at welding rates noted

rate of hits was changed without intermission, from three to six hits per minute.

Dynamic-Equilibrium Temperatures

Of the three tests discussed, two were continued until successive peaks had equal values. In Table I these tests are compared with temperature rises calculated by both duty-factor and duty-cycle methods. (The theoretical temperature rise for 21,000 amperes, found by methods beyond the scope of this paper, is 760 degrees centigrade.)

Since maximum averaging time for the cable is not known, duty-cycle computations were made for one hit cycle. If the averaging time were one-sixth second longer, the temperatures in the last column would be practically doubled, emphasizing the arbitrary nature of duty cycle and averaging time.

Figure 18 shows the tabulated results graphically. The agreement between test and duty-factor results is in marked contrast to the discrepancy found in "duty cycle."

Conclusion

By means of the simple charts derived from the duty-factor method of rating under periodic load, savings can be made:

(*a*). In designing new equipment.

(*b*). In applying new loads to existing equipment.

This is in line with engineering trends to load everything to full capacity, but not beyond.

The accuracy and easy application of duty-factor method recommend it for adoption, in conjunction with the heating time constant, as a standard method of rating equipment subject to intermittent loads.

Appendix

To use this duty-factor principle on other equipment, it is necessary to know the heating constants. Little has been published on this subject. The following have been taken principally from the papers listed in reference 4:

Power Transformers[4a]

Kilovolts	Megavolt-Amperes	Time Constant (Binary) (Hours)
13	1–5	1.7
34	8–20	1.9
69	1–2.5	3.0
69	5–33	2.1
110	5	2.6
	33	2.2
138	2.5–20	3.0
	33	2.5

Motors

One horsepower—23 minutes[4b]

One-half- to five-horsepower general-purpose induction—for heating 7 minutes—for cooling 35 minutes.[4c]

Thirty horsepower, three-phase six-pole induction, 500 rpm, 440 volts, 25 cycles—30 minutes.[4]

Fifty horsepower, direct current, four pole, 1,075 rpm, 230 volts—21 minutes.[4]

Ignitron

Small water-cooled ignitron[10]—16 seconds.

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Tests of 230-Kv High-Speed Reclosing Oil Circuit Breaker

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MEMBER AIEE

Synopsis: The advantages of high-speed reclosing of transmission lines in 20 cycles or less are well established for voltages up to 138 kv. Up to this date little information is available however on reclosing 230 kv lines in 20 cycles or less, because breakers have not been available for such fast operation. This paper describes a 230-kv oil circuit breaker which is suitable for three-pole or single-pole reclosing with a reclosing time of less than 20 cycles. The performance of the breaker is established by field tests for high-speed-reclosing operation as well as for interruption of charging currents.

IN the late 1920's, the increasing demand for fast-clearing circuit breakers brought forth the development of various types of modern arc-rupturing devices. Among others, there was developed the expulsion-chamber arc-rupturing device[1] which now is in satisfactory operation in thousands of breakers. The theory of expulsion action and the performance of the expulsion-chamber breakers have been reported on frequently. Test on a 115-kv system showed arcing times of approximately 1½ cycles at short-circuit capacities ranging up to 1,650,000 kva.[1] Tests on a 230-kv system showed arcing times of approximately 2.5 cycles at ratings up to 1,125,000 kva.[2] In the middle 1930's the practice of high-speed reclosing was introduced and is now widely accepted. Interrupting capacity tests performed on a 69-kv system showed that the expulsion-chamber arc-rupturing devices gave excellent performance in conjunction with high-speed-reclosing operation.[3] Following the demand for still shorter opening time, more recently five-cycle breakers have come into wide use. On highest voltages, particularly in conjunction with switching of long lines, the use of three-cycle breakers frequently is indicated.

Finally the method of single-pole reclosing on highest voltages in recent years has attracted considerable attention. Because of the wide distribution of 230-kv systems, it was therefore decided to subject a modern five-cycle high-speed-reclosing 230-kv circuit breaker to field tests, to analyze its performance generally and in particular with regard to the possibilities of developing a three-cycle breaker. Furthermore, it was hoped that the data would enable the drawing of conclusions as to a decrease in tank diameter, oil volume, and resulting reduction in cost. Through the courtesy of the Bonneville Power Administration, the North Bonneville Substation and four generators of the Bonneville power house were made available for these tests.

Paper 44-192, recommended by the AIEE committee on protective devices for presentation at the AIEE Los Angeles technical meeting, Los Angeles, Calif., August 29–September 1, 1944. Manuscript submitted June 1, 1944; made available for printing July 11, 1944.

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The author acknowledges the assistance of the engineering and operations departments of the Bonneville Power Administration in the performance of the tests described in this paper.

Description of Breaker, Operating Mechanism, and Test Connections

Breaker

The breaker tested consisted of a single-pole unit of a 196/230-kv circuit breaker with its high-speed-reclosing mechanism. Figure 1 shows a cross section through the breaker, which consists of six expulsion chambers arranged in series supported by the bushings. The movable blades are fastened to a vertically rotating bakelite tube. These blades move at speeds up to 28 feet per second, and therefore rapidly introduce a large break distance. The expulsion chamber resembles an explosion chamber; however, it radically differs in its action in that only moderate pressures are developed because of the provision of an expulsion port to the rear of the chamber. As previously explained,[1] the gases are accumulated to produce a more effective gas blast during the period of interruption. The oil volume within the chamber is kept small in order to prevent interference of large bodies of oil with the free escape of gases. However, an amount sufficient for multiple interruptions is provided. Figure 2 shows an expulsion chamber during the various stages of breaker opening.

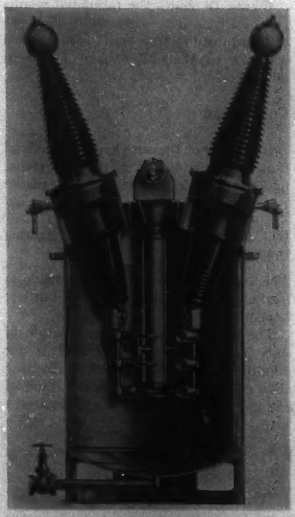
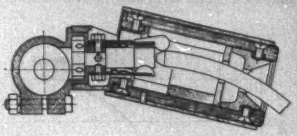


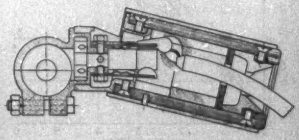
Figure 1. Cross-sectional view of the expulsion oil circuit breaker

Operating Mechanism

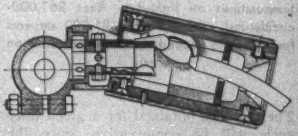
The operating mechanism is of the motor-wound spring-actuated trip-free type; its operating linkage corresponds to that of a solenoid control in which the closing coil and plunger are replaced by a prewound closing spring. When the



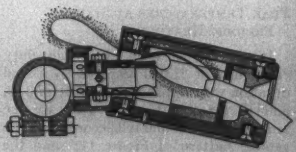
A. Contacts separate



B. Gas accumulating. No gas-blast action



C. Oil in expulsion port practically removed. No gas-blast action



D. Expulsion port cleared. High-velocity gas blast through the arc

Figure 2. Operation of expulsion chamber

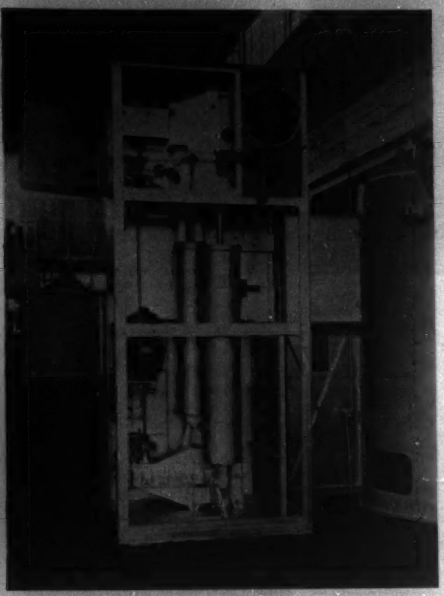


Figure 3. Operating mechanism

breaker is in the closed position, the closing spring also is wound and in case of opening of the breaker is available immediately to initiate the reclosing operation. Figure 3 shows the control applying to the breaker under test, the largest one of a line ranging from 7.5 to 230 kv. Figure 4 is a schematic diagram of the sequence of operation. The mechanism power is transmitted through a horizontal rotating shaft to the individual breaker poles and in each is transformed into the vertical breaker-shaft motion by means of a bevel link, which provides a toggle in the closed position, assuring perfect contact at all times.

During the opening or closing operation each blade provides a break of 24$^3/_4$ inches, the total with six breaks amounting to 148$^1/_2$ inches. During the reclosing operation the blades open to the full distance of 24$^3/_4$ inches each, insuring reliable and unimpaired performance during the first opening of the series. This feature is made possible by the high speed of blade travel. In order to obtain data concerning the required blade speeds for five-cycle and possibly three-cycle breakers, the test-breaker operating mechanism was provided with various spring combinations, giving opening velocities of from 18 to 28 feet per second. When connected to a three-pole breaker, the opening time (trip coil energized to arcing tips separate) amounts to 2.5 cycles or less; however, because only one pole was tested, a reduction in initial spring pressure was made, increasing the opening time to approximately three cycles. The reason for this is that the accelerating forces upon the trip levers also are reduced, increasing the time for the blades to proceed to the stationary-contact arcing tips. This deviation from three-pole oil-circuit-breaker conditions was of no consequence since the primary purpose of the test was to obtain arcing-time data. Opening times are determined readily by factory tests.

Test Setup

System connections and power sources

1. Single-phase short-circuit-to-ground opening and reclosing tests: two or four 60,000-kva generators feeding through transformers of corresponding kilovolt-amperes over one mile of 230-kv line. Voltage-recovery rates regulated by switching on or off 133 miles of 230-kv idle line.

2. Interruptions of line-charging-current tests: The 230-kv system charging 133 miles of 230-kv line. Tests were single pole, the other two phases being opened a few cycles before, simultaneously, or a few cycles after the test oil circuit breaker.

Equipment

A seven-element magnetic oscillograph was used to record all 60-cycle data, and the oil-circuit-breaker arc-tip position and opening travel. The arc-tip indicating contact was mounted directly on the oil-circuit-breaker rotating unit, eliminating any backlash and having entirely negligible deflection due to inertia effects. Switching voltages were measured by two methods. A sphere gap connected through a capacitance divider to the bushing capacitance tap, or a cathode-ray oscillograph similarly connected and fed through a concentric line. The latter was calibrated by over-all tests between one megacycle and 60 cycles and showed negligible distortion and attenuation in this range.

Breaker Tests

Tests were conducted during December 1943 and January 1944. Table I gives data on open and high-speed open–close–open shots.

Tests 1, 2, and 3 establish an arcing time of 1.8 cycles maximum for current values of around 870 amperes. Since the breaker rating of 2,500,000 kva corresponds to a rated interrupting current of 6,300 amperes, it can be seen that the breaker is capable of interrupting short-circuit currents considerably below 25 per cent maximum rating with an average arcing time of but 1.2 cycles.

Tests 13, 14, and 26 establish a maximum arcing time of 1.4 cycles for cur-

Table I. Short-Circuit Open and High-Speed Open–Close–Open Tests

Test Number December 19, 20, 1943	Duty Cycle	Kv to Ground Before Test; Phase C	Number of 60,000-Kva Generators	133 Miles of 230-Kv Line	Opening Speed, Ft Per Sec	Rms Amperes Interrupted	Total Time to Clear	Arcing Time	De-energized Time	Kva Interrupted, Equivalent 3 Phase	Cold Gas, Generated Gallons
1	O	143	2	On	28	850	3.9	1.0		364,000	No record
2	O	144	2	On	28	870	4.7	1.8		375,000	O
3	O	144	2	On	28	870	3.5	0.7		375,000	O
13	O	134	4	Off	28	1,910	4.2	1.4		766,000	1$^1/_4$
14	O	133	4	Off	28	1,860	4.1	1.2		742,000	$^1/_4$
26	OCO	1st opening 136	4	Off	23	1,900	4.5	1.4		775,000	1$^1/_2$
		2d opening	4	Off	23	1,970		0.5	12.6	805,000	

All times are in cycles at 60 per second. O—Open. OCO—Open–close–open.

Table II. Single-Phase Line-Charging-Current Interruption Tests

Line Kilovolts to Ground 127 to 130 Rms Amperes from 70 to 105

Test Number and Date	Opening Speed, Ft Per Sec	Resistors Across Expulsion Chambers	Backup OCB Phase A and B Open Before or After Phase C of Test OCB, Cycles	Cycles of Arc	Number of Restrikes	Ratio of Phase C Maximum Voltage to Normal Crest—Does Not Exceed: By Cathode-Ray Oscillograph	By Spark Gap
December 19, 1943							
15	28	No	0.2 before	1.0	1		
16	28	No	5.8 after	0.9	1		
17	28	No	10.1 before	1.2	1		
18	28	No	11.3 before	0.14	0		
19	28	No	11.2 before	1.1	1		
20	24	No	0.7 before	1.5	2		
21	24	No	1.3 before	1.2	1		
23	24	No	3.4 before	1.1	1		
24	24	No	1.7 before	1.2	1		
25	24	No	0.7 before	1.0	1		
January 9, 1944						Bus Side	Line Side
1	28	Yes	0.0 before	1.9*	0	1.2	1.36
2	28	Yes	1.4 before	2.1*	2	1.2	1.36
3	28	Yes	0.8 before	2.6*	0	1.2	1.36
4	21.5	Yes	0.5 before	3.0*	0	1.2	1.36
5	21.5	Yes	0.5 before	2.9*	0	1.2	1.36
6	21.5	Yes	1.1 before	2.2*	0	1.2	1.36
7	18	Yes	3.7 before	2.8*	0	1.2	1.36
9	18	Yes	3.4 before	3.1*	1	1.2	1.36
10	18	Yes	3.6 before	3.3*	2	1.2	1.36
11	28	No	7.0 after	1.14	1	1.1–1.2	1.36
12	28	No	7.1 after	0.8	1	1.1–1.2	1.36
13	18	No	5.3 after	2.0	3	1.1–1.2	1.36
14	18	No	5.0 after	1.1	1	1.1–1.2	1.36
15	18	No	5.6 after	1.4	2	1.1–1.2	1.36
						Line Side	
16	18	No	4.6 after	1.2	3	1.55	Discontinued

All times are in cycles at 60 per second. * Arc tips part to final clearing. OCB—Oil circuit breaker.

rents above 25 per cent of full breaker rating for operating speeds as low as 23 feet per second. Since no lines were connected during these tests, the rates of rise of recovery voltage were high, and the tests represent a condition more severe than can be expected during normal operating conditions. The maximum current interrupted is considerably below the rated interrupting current; however, previous published tests on a 115-kv system up to 10,000 amperes have established the fact that the arcing time decreases with increasing current. This decrease in arcing time is due to the fact that higher currents generate gases at an increased rate, producing a more effective gas-blast action. Important loads precluded the possibility of tests including the entire system. However, since the performance of the expulsion chambers at higher currents is so well established, it may be assumed that such tests could not but conform.

Test 26 represented by oscillogram, Figure 5, gives performance under high-speed-reclosing conditions. The reclosing time amounted to 17 cycles, the de-energized time to 13 cycles. The first interruption occurred with an arcing time of 1.4 cycles, the second one with an arcing time of only one-half cycle.

Much effort has been spent in recent years to produce rupturing devices for high-speed-reclosing oil circuit breakers with the purpose of reducing the arcing time of the second interruption to that of the first one. In considering the expulsion chambers, it could be assumed that a definite amount of time is required for the chamber to recover its interrupting ability. However, since these chambers are operating on the gas-blast principle and require but a small amount of oil for each interruption, and since a liberal amount of oil is present in the expulsion chamber, it can be anticipated that the chamber requires no recovery time at all. This assumption is verified by the short arcing time of only one-half cycle during the second opening.

During all the aforementioned tests, the vent pipe was completely closed off by a deflated paper bag. The amount of inflation of this bag represents a simple means of approximating the volume of gases produced during each interruption.

Figure 4. Operating-mechanism linkage

A. Breaker closed

Closing spring and opening spring charged, ready for trip, immediate reclose, and second trip cycle

B. First opening

Trip-coil plunger trips trip toggle which starts resetting as soon as pin *A* of main linkage has cleared prop. Opening spring opens breaker and brings pin *A* into vicinity of closing lever which is released by means of closing-coil plunger

C. Closing

Upon release of closing lever (Figure 4B), breaker is closed and prop engages pin *A*. Trip coil is again energized and plunger breaks opening link which resets as soon as pin *A* has cleared prop and pawl on closing lever

D. Second opening

Breaker opens as in Figure 4B, and motor limit switch energized turning crank one revolution, resetting closing lever on closing latch and charging spring

When breaker is closed and remains closed, motor again turns crank one revolution, bringing control to original position, Figure 4A, ready for immediate-reclosing cycle

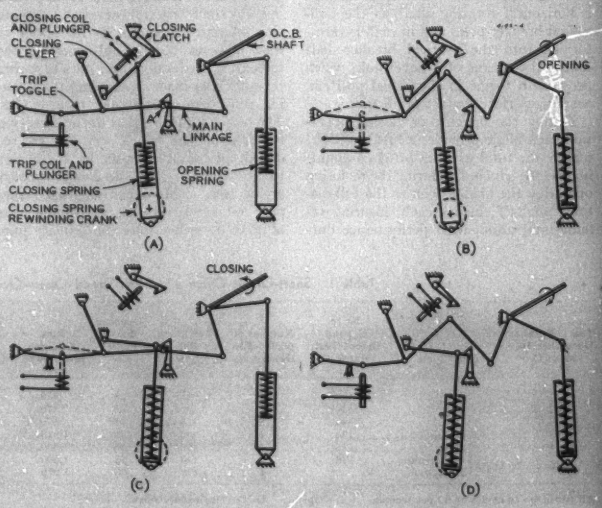


Figure 5. Magnetic oscillogram of reclosing test 26, December 20, 1943

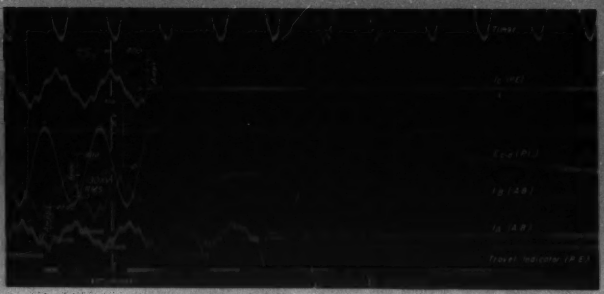


Figure 6. Magnetic oscillogram of charging-current interruption, test 15, December 19, 1943

As can be seen from the last column of Table I, the maximum amount was 1½ gallons. The inflation of this paper bag was the only visible evidence of the interruption; no disturbance was noticeable during any of these tests.

Charging-Current-Interruption Tests

During these tests, one phase of a three-phase line charged by the substation bus was opened by the test breaker; the other two phases were opened a few cycles before, simultaneously, or a few cycles after by a station breaker.

It has been recognized for a long time that the interruption of charging currents of long transmission lines represents the severest duty that can be imposed upon a circuit breaker.[4] The theory of restrikes and the subsequent building up of high overvoltages has been reported upon in detail[5] and requires no further discussion here. Recent investigations show that breakers equipped with most modern arc-rupturing devices can produce overvoltages in excess of 4½ times normal voltage, because of multiple restrikes, and that these voltages can be reduced to harmless values of twice normal voltage by the provision of resistances across the interrupting devices.[6]

Accordingly, parallel resistances of 500 ohms were built for installation across each of the six expulsion chambers. Tests were performed with and without resistances; in addition, the opening speed was varied. Table II gives the results of the charging-current-interruption tests.

Of interest is the very short arcing time without use of resistances and its increase with decrease in opening speed. At 28 feet per second speed, without resistances the number of restrikes was limited to one, at 24 feet per second two restrikes occur in one case out of 5, and at 18 feet per second the maximum number of restrikes amounts to 3. Resistances eliminate the restrikes except for small suppressed restrikes, but result in an increase in effective arcing time to values as high as 3.3 cycles against a maximum time without resistances of two cycles. Voltage measurements by cathode-ray oscillograph and spark gap show a maximum possible value of 1.36 times normal voltage. No voltage records were taken during the December 19 test; however, since the highest voltages are likely to occur at the lowest operating speeds and corresponding maximum number of restrikes, it is felt that the omission is not important. The behavior of the expulsion chamber in interrupting charging currents in such short times without the use of resistances or other auxiliary devices seems to justify a detailed study of the causes of this unusual performance.

Considering the mechanism of generation of overvoltages by the restrikes, it may be proved that to prevent such overvoltages the reignition voltage should be less than the normal line-to-ground voltage. Since the voltage builds up to the normal value within one-quarter cycle, the current-zero period should be one-quarter cycle or less. Only those restrikes in which the current-zero interval exceeds one-quarter cycle will cause overvoltages. Numerous successive delayed restrikes with current-zero intervals of less than one-quarter cycle are therefore harmless, as is evidenced by operating experience on numerous plain-break breakers known not to produce harmful overvoltages.

An arc-rupturing device therefore should have a very low dielectric-recovery rate, permitting restrikes within less than one-quarter cycle after current interruption until such time that the device is capable of withstanding full voltage. Since in the gas accumulation period, the expulsion chamber constitutes a plain-break switch and since in the low-current range this period amounts to approximately one cycle, an early and harmless restrike can be expected. After this period the gas-blast action starts and causes final interruption of the arc at the next current zero.

Figure 6 shows an oscillogram of the interruption corresponding to test 15,

December 19, at a speed of 28 feet per second. A restrike occurs in less than one-quarter cycle after the first current zero to be followed by final interruption. Similar performance with not more than one restrike was obtained on all interruptions with a speed of 28 feet per second. Opening speeds of 24 feet per second as shown from test 20, December 19, can produce two restrikes of which the second one can be preceded by a zero-current interval in excess of one-quarter cycle. However, even if the delay amounts to the critical one-half cycle period, the theoretical voltage cannot exceed three times normal line voltage. Actual voltage measurements during operations with opening speeds as low as 18 feet per second and a maximum of three restrikes did not indicate any appreciable overvoltage.

The expulsion-chamber breaker, when operated with speeds above 24 feet per second, interrupts charging currents without producing overvoltages. Operation at lower speeds, although theoretically capable of producing overvoltages of three times normal, does not produce harmful values.

Conclusions

1. The expulsion-chamber rupturing devices are capable of interrupting short circuits on a 230-kv system in less than 1.5 cycles, making expulsion oil circuit breakers having an interrupting time of considerably less than five cycles a possibility.

2. Successive interruptions during high-speed-reclosing operations with only 13 cycles de-energized time are handled without difficulty by the expulsion chamber.

3. The expulsion chambers are suited ideally for the interruption of charging currents. The arcing times are small, and no harmful overvoltages are produced. Parallel resistances can be applied to expulsion chambers; however, they produce no improvement in performance.

4. The motor-wound spring-actuated operating mechanism produces reclosing speeds not heretofore reached and permits full opening of the breaker during all reclosing operations.

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Operation of Low-Pressure Gas-Filled Cable

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SINCE 1938 low-pressure gas-filled cable has been the source of considerable discussion before meetings of the Institute and other technical associations. Papers presented by Shanklin in 1939[1] and 1942[2] and an unpublished paper by Del Mar and Gambitta in 1943 discussed the theoretical aspects of a cable utilizing gas as pressure medium and presented extensive laboratory test data on the expected life of this type of cable. From these data it was indicated that if low-pressure gas-filled cable is operated at an average stress of less than 75 volts per mil and at a minimum gas pressure of ten pounds per square inch satisfactory operation may be expected.

Theories and laboratory test data are not always sufficient to establish a fact and they should be substantiated by actual field data whenever possible to prove the theory. It is intended in this paper to present factual data on the actual operation of low-pressure gas-filled cable of various types on the system of the Consolidated Edison Company of New York, Inc. Operating experience data in the report are divided into (1) sheath experience and (2) electrical quality of the insulation of cable removed from service.

History of Installation

In view of the satisfactory operation of oil-filled feeders installed in 1927 and 1929 where for the first time complete sheath supervision was obtained, it seemed apparent that if supervision could be maintained over the lead sheaths of solid-type cables a large percentage of electrical failures could be eliminated. The low-pressure gas-filled cable described by Shanklin in his 1939[1] paper appeared to offer a satisfactory solution to this problem of sheath supervision, for feeders operating at medium voltages, such as 15,000 volts and 27,000 volts and in addition appeared to provide greater stability against ionization. With this type of cable, positive pressure could be maintained within the cable thereby reducing the possibility of water entering the cable in the event of sheath or joint defects and providing a means of indicating when sheath or joint defects occurred.

In order to obtain information on actual field operating conditions there was installed on the Consolidated Edison system during the year 1938 approximately 20,000 feet of three-conductor 800,000-circular-mil 15,000-volt low-pressure gas-filled cable. The operation of the initial 1938 installation was followed closely in the field and the results obtained appeared to check factory laboratory results. To obtain additional information on this low-pressure gas-filled cable at

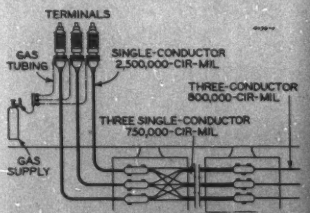

Figure 1. Typical installation of gas-filled cable at generating stations

Connection of single-conductor to three-conductor cable

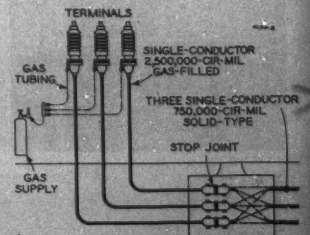

Figure 2. Typical installation of gas-filled cable at generating stations

Connection of gas-filled to solid-type cable

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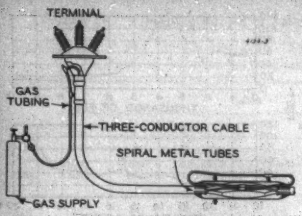

Figure 3. Connection of solid-wall tubing to joints and terminal

higher operating voltages, there was installed during 1939 approximately 8,000 feet of three-conductor 500,000 circular-mil 27,000-volt cable.

The construction program for the year 1940 involved extensive feeder rearrangements around several generating stations and the installation of additional 27,000-volt feeders between generating stations. The information which had been obtained from the 15,000-volt cable installed during 1938 and the 27,000-volt cable installed during 1939 indicated that the low-pressure gas-filled cable would be a desirable type of cable for the new cables required at he generating stations as it was desired to obtain cables where supervision could be maintained over the lead sheaths. The cables required for station lengths at the generating stations were of the single-conductor type so as to obtain phase isolation in accordance with our standard practice in generating stations. The cable manufacturers were approached at this time as to the possibility of obtaining single-conductor low-pressure gas-filled cables as all of the past experience had been obtained on three-conductor gas-filled cable. Agreement was reached on the type of single-conductor cable to be used for low-pressure gas-filled cables and our requirements for the feeder rearrangements at the generating stations were purchased as low-pressure gas-filled cable.

All of the low-pressure gas-filled cable installed on the system between 1938 and 1940 was in relatively short runs, the maximum length being approximately two miles. Runs of this length presented no serious difficulty in maintaining proper gas pressure along the entire run of cable with one point of supply. In 1941 it was decided to install a feeder from one of our generating stations to a substation approximately six miles away. Three-conductor 800,000-circular-mil 15,000-volt gas-filled cable was purchased and installed for this feeder and a single point of supply was provided for maintenance of gas pressure.

Table I. Cable Operating Under Nitrogen Pressure (13 Pounds Per Square Inch) on System of Consolidated Edison Company of New York, Inc., and Affiliated Companies

Cable Feet as of June 1, 1944

Number of Conductors	Size, Thousands of Circular Mils	Rated Voltage 27 Kv	15 Kv	Total
1	750		1,100	1,100
1	1,000	9,650	30,000	39,650
1	2,500	1,500	7,400	8,900
3	500	38,625		38,625
3	800		49,800	49,800
		49,775	88,300	138,075

Types of Cable and Cable Arrangements

As of June 1, 1944, the total amount of low-pressure gas-filled cable installed on the system is as shown in Table I.

As indicated in Table I several sizes and types of cables have been used. In general it has been necessary to use several different sizes of single-conductor cable at generating stations in order to make optimum use of existing ducts, to obtain space for terminations, and to utilize existing solid-type cables. No difficulty has been experienced in using gas-filled cable for paralleling lengths of cable, connecting a large single-conductor cable to several smaller cables, or connecting to solid cables. Typical installations of gas-filled cable at generating stations and connections to solid cable are shown on Figures 1 and 2.

Method of Installation

The three-conductor cable which was installed during 1938 was manufactured with three spiral tubes in the interstices. Due to oil drainage from the paper insulation, oil slugs were formed in the spiral tubes causing partial blockage of the channel spaces and preventing free flow of the nitrogen gas along the entire length of the feeder from the one point source of supply. On all subsequent three-conductor cable which has been purchased, a solid-wall copper tube for one of the three gas channels has been specified. This solid-wall tube is connected into each joint in a manner which prevents the entrance of cable compound into the tube and supplies a point of feed to the cable as shown by Figure 3. This method provides a gas supply manifold along the entire route of a feeder since the source of gas supply, namely, a cylinder of nitrogen, is connected to a terminal or joint where the solid-wall tube ends. This type of construction provides continuous supply of gas to every individual joint and tends to maintain uniform pressure along the line.

In single-conductor gas-filled cable, channels for the flow of gas were obtained by two methods: (1) the application of a button-embossed copper tape between the cable core and the lead sheath, and (2) by the use of fluted lead sheath. Figure 4 shows the two types of construction of single-conductor cable.

At the time of the installation of the original gas-filled cables at the generating stations, gas-filled terminals were not available. Development work had not progressed to the point where manufacturers were willing to guarantee clearances within the terminals with only nitrogen gas as a filling medium. In order to carry the gas-filled cable into

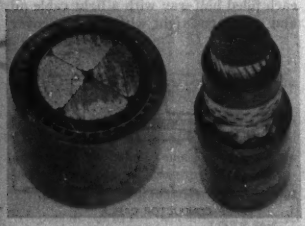

Figure 4. Provision of gas space in single-conductor cable by use of fluted lead sheath or button-embossed spacer tape

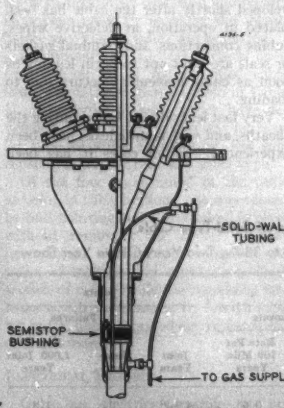

Figure 5. Three-conductor compound-filled terminal for use on gas-filled cable

Table II. Classification of Leaks

	Total Number Installed	Number of Leaks
Terminals	350	30
Relays	24	8
Fittings		19
Normal joints	581	8
Stop joints	46	0
Gas-supply equipment	24	30
Cable sections	759	4
Cable adjacent to joint		48
Not located		18
Total leaks		163

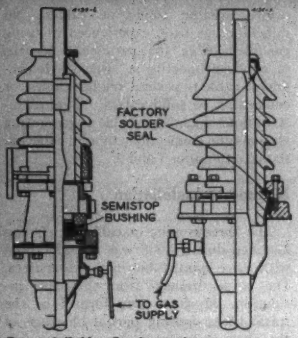

Figure 6 (left). Single-conductor compound-filled terminal for use on gas-filled cable

Figure 7 (right). Single-conductor gas-filled solder-seal terminal for use on gas-filled cable

terminals a standard-type terminal was used with a semistop feature incorporated in the wiping sleeve of the terminal. The semistop feature was installed to prevent the filling compound within the terminal from flowing into the gas-filled cable. This semistop feature did not in all cases prevent the gas from entering the terminal after it had been completely installed. All of the original terminals which were used were of the normal gasketed type. Figures 5 and 6 show the terminals used for three-conductor and single-conductor cable with the semistop features which were incorporated in the wiping sleeves. Considerable difficulty was experienced with leaks at the gaskets in these terminals. Terminals which were initially tight developed leaks after the gaskets had been subjected to working when the cables were loaded. In order to eliminate this source of trouble development work was continued by the manufacturers on gas-filled terminals with the final result that there became available gas-filled solder-seal-type terminals which eliminated all gaskets. On recent installations of single-conductor gas-filled cable at stations, this type of terminal has been used. Figure 7 shows such a gas-filled terminal.

Types of Installations

There are now in service on the Consolidated Edison system 21 feeders which are composed in part of gas-filled cable. The feeder which includes the longest continuous run of gas-filled cable is one which operates at 13.2 kv and is composed of three-conductor 800,000-circular-mil cable extending a distance of approximately 33,000 feet from a point near the Sherman Creek generating station to the Columbus Avenue substation of The Yonkers Electric Light and Power Company in Yonkers, N. Y.

Another feeder 7,500 feet in route length is composed of three legs of 27-kv cable from the East River generating station to a submarine crossing across the East River. There are also two three-conductor 27-kv feeders approximately 5,600 feet in length which extend from the Hell Gate generating station to the Queens district. These two feeders are installed through a tunnel underneath the East River and have vertical riser lengths of approximately 250 feet at each end. Most of the remaining 17 feeders have relatively short sections of gas-filled cable adjacent to the stations which is predominantly single-conductor cable. Because of this use as station legs there is a considerable number of terminals in proportion to the length of cable involved. Figure 8 shows a typical profile of one of the feeders and Figure 9 shows the profile of a feeder through a tunnel.

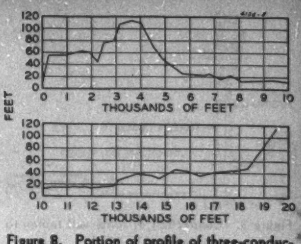

Figure 8. Portion of profile of three-conductor 800,000-circular-mil 13.2-kv gas-filled feeder

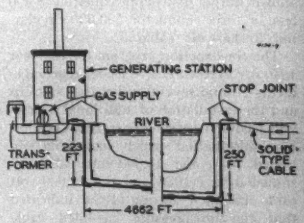

Figure 9. Profile of three-conductor 500,000-circular-mil 27-kv gas-filled feeder installed in tunnel under East River

Operation

Mechanical Trouble

Gas leaks have developed from time to time in the cable joints and terminals. In general, with one outstanding exception, it can be said that leaks have developed shortly after the cable has been placed in operation, as defective wipes, tubing connections, and terminal gaskets or seals are most apt to begin leaking as soon as cable movement occurs due to loading.

Very fast leaks due to bull-pointing the sheaths, and very minute leaks have been experienced. In all cases it has been possible to maintain gas pressure until the leak has been found and repaired.

The approximate location of leaks is normally determined by the pressure-drop method; that is, a fixed pressure is maintained at both ends of a known run of cable and pressure is measured at the intervening joints. The point of lowest pressure is the approximate location of the leak. The application of liquid soap to all exposed parts of the system at this location will then reveal the actual point of leakage if it is outside of the conduit run. In order to reduce the time required to locate a leak on a long run of three-conductor cable, gas-flow direction indicators are permanently installed at specified intervals so that the direction of gas flow past these points can be determined.

The indicator consists of two glass jars, each filled half-way with a light cable oil and sealed gas tight with a metal cover

Table III. Operating Record of Solid-Type Cable

Three-Conductor and Single-Conductor, 15-Kv to 33-Kv, Two Years Old in Year Shown

	Cable					Joints		
		Failures		Removals			Failures	
Year	Mile Years	Number	Rate Per 100 Mile Years	Number	Rate Per 100 Mile Years	Joint Years	Number	Rate Per 1,000 Joint Years
1940	170	13	7.7	1	0.6	4,942	9	1.8
1941	180	11	6.9	0	0	4,428	10	2.3
1942	253	9	3.6	1	0.4	7,522	7	0.9

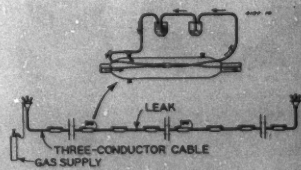

Figure 10. Installation of gas-flow direction indicators on three-conductor cable for location of gas leaks

Table IV. Operating Record of Solid-Type and Gas-Filled Cable Combined

Three-Conductor and Single-Conductor, 15-Kv to 33-Kv, Two Years Old in Year Shown
(Assuming Failures Had Resulted From One-Half the Gas Leaks)

	Cable					Joints		
		Failures		Removals			Failures	
Year	Mile-Years	Number	Rate Per 100 Mile-Years	Number	Rate Per 100 Mile-Years	Joint-Years	Number	Rate Per 1,000 Joint-Years
1941	161	12	7.5	0	0.0	4,454	11	2.5
1942	263	11	4.2	1	0.4	7,798	9	1.2

and gasket. The two jars are connected in series and are inserted in the solid wall gas tube of the cable at a joint location. Under normal conditions when there is no flow of gas in the cable the oil in the two glass jars remains at the same level. When there is a flow of gas due to a leak gas will flow from the supply tank into the indicator forcing all of the oil into the glass in the direction of the leak. The direction of gas flow is also indicated by bubbles rising to the surface of the oil in the jar in the direction of the leak. The indicator and a typical installation are shown in Figure 10. With this method a leak can very readily be located between two indicator locations and the pressure-drop and liquid-soap method used for definite location within the section.

On the installations of parallel lengths of single-conductor cable at generating stations the gas supply from a common tank to individual cables has been carried through valves. When a leak is indicated by loss of gas from the tank the particular length of cable which is leaking can be determined by operation of the valves.

In very serious cases of sheath rupture it has been possible to maintain gas pressure and continue operation of a feeder. The 13.2-kv Sherman Creek feeder previously referred to as being the longest run of gas-filled cable was placed in service in October 1941. Prior to 1943 due to system operating conditions it carried little or no load. During 1943 it became necessary to load the cable to its normal load for approximately 20 hours each day with very light loads for the remaining 4 hours. With this load cycle, movement of cable in the manhole occurred and due to cable arrangement in the manhole the sheath was buckled and cracked.

Subsequent to finding the first sheath breaks a survey was made of the manholes and it was found that in 74 per cent of the manholes inspected the cable sheath was buckled adjacent to the joint wipe. Breaks have occurred in these buckles in approximately one-fourth of the manholes. The same sheath failures would have occurred in solid cable of the same conductor size installed under the same conditions and would without doubt have been responsible for a number of electrical failures.

The leaks have been found by the methods previously described and repairs have been made by patching the sheath before any known water was admitted.

A summary of all leaks which have occurred on all of the gas-filled cable installed on the system is shown in Table II. The types of leaks which have developed do not indicate that any particular type of cable is more or less susceptible to trouble than any other type.

Of the four leaks noted in the table as being in cable sections, one was caused by bull-pointing and was repaired in place without removing the cable; another necessitated cutting the cable at the point of leakage and replacing a short section of cable, while the remaining two leaks which were caused by foreign matter in the ducts required the replacement of the sections.

Electrical Trouble

Only one electrical trouble has occurred on the gas-filled cable. This fault was a test failure on a single-conductor 15,000-volt cable which had been severely damaged during installation. Examination of the fault indicated that approximately half of the paper tapes had been broken and torn by a severe twist and failure occurred at the point of broken tapes when a proof test was applied prior to placing in service.

No service failures have occurred in any of the 138,000 feet of gas-filled cable installed on the system.

That electrical failures could have been expected on this amount of cable, had it been of the solid type instead of gas filled, is indicated by the data contained in Table III. This table gives the failure rates in 1940, 1941, and 1942 of solid-type cable of comparable voltage rating which was two years old in those years.

For purposes of comparison Table IV shows for 1941 and 1942 the estimated failure rates which would have obtained if gas-filled cable had not been used and one half of the gas leaks found in cable sections and joints had resulted in failures during this two-year period of operation. That none of the gas leaks did cause failures may be attributed to the advantage of sheath supervision whereby sheath breaks are quickly discovered.

Electrical Characteristics

Manufacturers' laboratory test data have indicated that ionization will not take place in gas-filled cable if it is operated below an average stress of 75 volts per mil and with a minimum gas pressure of 10 pounds per square inch. All gas-filled cable operating on the Consolidated Edison Company system is supplied normally with gas at 13 pounds per square inch pressure and in case of a leak the pressure may drop to a minimum of 8 pounds per square inch for a short period of time.

The average stress for the cables ranges

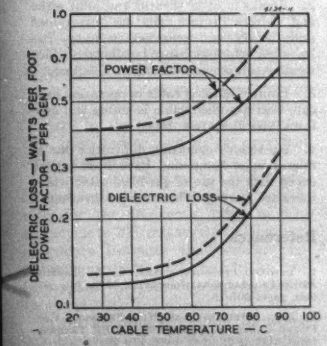

Figure 11. Power factor and dielectric loss at 27 kv of three-conductor 500,000-circular-mil gas-filled cable before being placed in service and after one year of operation as generating-station tie feeder

Ten pounds per square inch nitrogen pressure, 225-mil insulation

Solid curves—Before placing in service

Dashed curves—After one year in service

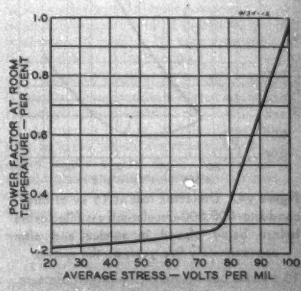

Figure 12. Ionization at room temperature of three-conductor 500,000-circular-mil 27-kv gas-filled cable after one year of operation as generating-station tie feeder

Ten pounds per square inch nitrogen pressure, 225-mil insulation

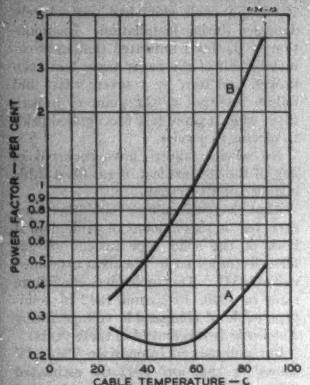

Figure 13. Power factor at 15 kv of three-conductor 800,000-circular-mil gas-filled cable before being placed in service and after approximately five years on the system

16 pounds per square inch nitrogen pressure, 150-mil insulation

A—Before placing in service

B—After 15 months loaded, 17 months dead, and 27 months loaded

between 39 volts per mil as a minimum and 68 volts per mil as a maximum. In order to determine if any ionization is taking place two sections of cable have been withdrawn for measurement of power factor and losses and for a visual examination of the papers.

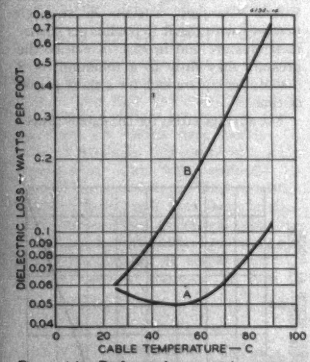

Figure 14. Dielectric loss at 15 kv of three-conductor 800,000-circular-mil gas-filled cable before being placed in service and after approximately five years on the system

16 pounds per square inch nitrogen pressure, 150-mil insulation

A—Before placing in service

B—After 15 months loaded, 17 months dead, and 27 months loaded

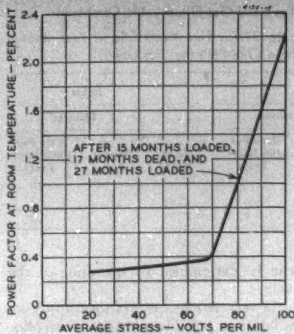
POWER FACTOR AT ROOM TEMPERATURE — PER CENT
AVERAGE STRESS — VOLTS PER MIL
AFTER 15 MONTHS LOADED, 17 MONTHS DEAD, AND 27 MONTHS LOADED

Figure 15. Ionization at room temperature of three-conductor 800,000-circular-mil 15-kv gas-filled cable after approximately five years on the system

After 15 months loaded, 17 months dead, and 27 months loaded

A 320-foot length of three-conductor 500,000-circular-mil 27,000-volt cable having 225 mils of paper insulation was removed from service after one year of operation at 27,000 volts. This cable had been operated as part of a tie feeder between generating stations.

Power-factor and dielectric-loss measurements were made on the section of cable and are shown in Figure 11 with the original factory measurements for comparison.

The power factor measured at room temperature at various volts-per-mil stress is shown in Figure 12. The ionization at 85 volts per mil after one year of operation is in agreement with data obtained from approximately 200 days of laboratory load cycle tests.

Visual examination and power-factor measurements of the paper tapes from the cable did not reveal any indication of deterioration. The five paper tapes nearest the conductor contained a few streaks, about the original color of the paper, which were more pronounced in the paper nearest the conductor. It was generally agreed that the streaks were not wax but possibly some form of oxidation products.

A 275-foot length of three-conductor 800,000-circular-mil 15,000-volt cable having 150 mils of paper insulation was removed from service after having been on the system for approximately five years. During this period the cable was operated for 15 months at an average stress of 44 volts per mil; was out of service for 17 months; and then was operated again for 27 months at an average stress of 53 volts per mil.

Power-factor and dielectric-loss measurements were made on the section of cable and are shown in Figures 13 and 14, respectively.

The power factor measured at room temperature at various volts per mil stress is shown in Figure 15.

Visual examination and power-factor measurements of the paper tapes from the cable did not reveal any indications of deterioration.

Examination of the dielectric-power-factor values shown in Figures 11 and 13 shows a greater increase in power factor for the 15,000-volt cable which had been on the system for approximately five years. With the exception of a longer period of operation the only different operating condition between the 15,000-volt cable and the 27,000-volt cable was in the amount of nitrogen which was injected into the cable after installation. Some leaks occurred on the 15,000-volt line necessitating feeding nitrogen into the line to maintain proper gas pressure thereby subjecting the insulation to exposure to a greater volume of nitrogen containing some traces of oxygen. It is possible that the insulation may absorb the oxygen from the nitrogen and an oxidation action take place resulting in an increase in power factor. This action may be the cause of the higher power-factor values for the 15,000-volt cable.

Conclusions

1. Operating experience to date has shown that electrical failures commonly experienced on new installations of solid-type cable have been eliminated by the use of gas-filled cable.

2. Breaks in cable sheaths and joint wipes and defects in terminals are ascertained immediately and remedial measures can be taken before moisture is admitted which would result in eventual electrical failure.

3. Limited data on cable in operation indicate that gas-filled cable is stable and confirms laboratory test data.

4. No serious operating difficulties due to migration of compound have been experienced with the use of gas-filled cable where there are marked differences in elevation.

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Radio-Noise Elimination in Military Aircraft

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RADIO noise may be defined as radio-frequency energy which interferes with the reception of desired signals. This interference can be the result of:

1. Atmospheric electrical discharges which result in radiated radio frequency energy.

2. Periodic corona discharges from the airplane which cause intense electric induction fields close to the receiving antennas.

3. Receiver internal noise due to thermal agitation in the receiver input resistance and shot effect in the low-level radio-frequency stages.[1]

4. Electrical transients which result from the operation of electrical equipment.

Methods of reducing the first two types of disturbances are still in the experimental stage and are not within the scope of this paper. The third type of noise is inherent in the receiver, being dependent upon receiver sensitivity, band width, and general design. This, of course, is determined by the functions which the receiver must perform.

The fourth type of noise is due to electrical transients in commutating machines, ignition systems, and other current-interrupting devices, which contain harmonic components extending into the radio-frequency spectrum. Satisfactory receiver operation dictates that this latter type of noise be suppressed or reduced to a point where the operation of electric equipment will have a minimum effect on radio communication. However, filter and shielding weight must be kept to a minimum. Therefore, radio design must be a compromise between desired radio performance and the limitations imposed by the requirements of installation, maintenance, and weight prevalent on present aircraft.

The recommendations and design procedures outlined in this paper are specifically for the frequency range of 0.16 megacycle to 20.0 megacycles. However, experience indicates that similar procedures, methods, and precautions may be applied to the ultrahigh-frequency spectrum.

In the following discussion, all wiring is considered unshielded except ignition circuits or those circuits where conduit is required for mechanical protection. The airplane is assumed to be of all-metal construction.

Radio-Noise Coupling to the Receiver

The radio-frequency energy components, coming from the various electrical transients, are induced into the receivers by various methods.

1. Radio-noise voltages generated by current-interrupting devices may be conducted into the receiver by means of the common power supply. This conducted noise is then coupled to the radio-frequency stages and results in noise in the receiver output.

2. The power wiring in the fuselage of the airplane conducts radio-frequency currents and voltages generated by the electric equipment. This results in radio-frequency induction fields which may be of large enough magnitude to induce, by magnetic or capacitive coupling, radio-frequency noise energy into the receiver-antenna leadin. Solution to this type of radio-noise problem is to reduce the mutual coupling by rerouting wiring and, if necessary, by electromagnetic shielding.

3. The ignition system of the airplane periodically (depending upon the engine speed and number of spark plugs) sets up steep-wave-front voltage discharges each time a spark plug is fired. This voltage discharge contains measurable components up to 450 megacycles.[2] The wave front of the discharge and subsequent oscillation is dependent upon the distributed circuit parameters in the high-voltage side of the ignition system.

The radio-frequency fields associated with the steep-wave-front discharges are shielded from the antennas by enclosing the magneto, distributors, and high-voltage leads with metal shielding. Efficiency of this harness shielding is dependent upon high conductivity of the entire metal enclosure. High-impedance joints between harness assemblies result in a decrease in effective shielding. Also, unless the harness is securely bonded to the airplane structure, the entire ignition harness will tend to radiate and produce resulting radio-frequency fields at the receiving antennas.

Designing for Radio-Noise Elimination

The performance of the radio equipment in the airplane is the final test of a satisfactory electrical and radio installation. Carefully tested electrical equipment which has been limited to a specified over-all radio noise voltage in the laboratory may, upon installation in the airplane, acquire a different radio-noise frequency distribution and unpredicted peaks.

It would then appear that laboratory testing is of limited value and that the prototype airplane must be tested and altered as required for satisfactory radio performance. The results of the tests could then be incorporated into the production airplanes. Although this method of design is good engineering, in actual practice there are many drawbacks to this method. Where production is of prime importance it is very difficult to effect changes after an airplane is in production. This is especially true in the case of electrical accessories. Installation of filtering on motors usually requires a redesign of the motor frame. Therefore, a compromise must be evolved whereby a maximum amount of radio design is accomplished prior to the completion of an airplane. This necessitates close co-operation between the radio engineer and the project electrical engineer.

Basic Radio-Installation Design

The following principles of design should be incorporated on the engineering drawings at the time when the electrical and radio systems are being developed:

(*a*). Antenna lead-ins must be kept as short and direct as possible. A compromise should be effected between structure shielding and a low capacitance lead-in.[3]

(*b*). The designer should strive for a maximum spacing between the antenna lead-in and electrical wiring.

(*c*). Great care must be exercised in bonding the receiver chassis to the airplane structure. The bonding straps must be as short as possible and the bonding must be made to basic structure. Too often radio-noise coupling to the antenna input circuit is a result of poor receiver bonding.[4]

(*d*). Sources of radio noise such as commutating motors and pulsing relays should not be installed close to radio equipment.

(*e*). All radio and interphone wiring should be in bundles separate from power wiring. A minimum separation of 12 inches should be maintained if possible between communications and power wire bundles.

(*f*). Antenna location on military aircraft is usually a compromise dictated by desired radiation characteristics, the need for a short antenna lead-in, and locations available in areas which are removed from the cones of fire of the guns. Consideration should also be given to locating antennas a maximum distance from the airplane engines.

Threshold of Conducted Radio Noise

It is desirable to reduce conducted radio noise to a level not greater than the internal noise of the receiver at maximum sensitivity.

The allowable conducted radio-noise level that will fulfill this condition must be known to permit proper filter design. This can be determined by the setup

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G. Weinstein, H. H. Howell, G. P. Lowe, and B. J. Winter are in the engineering division of Boeing Aircraft Company, Seattle, Wash.

shown in Figure 1. Curves of power-line noise in microvolts versus receiver output in decibels can be obtained at various frequencies for each receiver. One such curve at 340 kilocycles is illustrated in Figure 2. From curves similar to Figure 2, a new curve can be derived of threshold of conducted radio noise versus receiver frequency. Threshold of conducted radio noise is defined in this paper as that value of noise voltage which increases the receiver output one half decibel above the internal noise with no signal applied. A curve of this type is shown in Figure 3. In this manner, the allowable conducted radio-noise level at the receiver can be determined in advance of the completion of the airplane.

Methods of Filtering Conducted Radio Noise

The choice of an airplane radio-noise-filter system should be governed by the following general considerations:

(*a*). The conducted radio-noise voltage level at the power input to the receiver must be within the applicable threshold levels.

(*b*). The coupling between the antenna leadin and the induction fields set up by the conducted radio noise must be kept to a minimum. Filtering exceeding the requirements of the threshold of conducted radio-noise curve specified in Figure 3, may be necessary to achieve a reduction in the radio-frequency noise induced into the antenna leadin.

(*c*). Filter weight must be kept to a minimum.

(*d*). Many changes in electrical and radio equipment are made on an airplane after it has been delivered to the customer. This problem should be recognized by the radio engineer and a safety factor allowed in his design.

There are a variety of approaches to the problem of achieving suppression of radio noise from electric equipment. General classifications are discussed as follows:

(*a*). *Receiver Filtering*. Filters may be inserted in the d-c power input to the receiver. The attenuation of the filter must be sufficient to reduce the radio-noise level below the threshold of conducted radio noise. However, this method has the following disadvantages:

1. Changes in electric equipment after the airplane has been delivered may result in a high radio noise level.

2. The requirement of low coupling of radio noise fields to antenna lead-ins is difficult to achieve without additional filtering on the power line.

(*b*). *Source Filtering*. Sources of radio noise have been limited by service specification to the equipment manufacturer to a value not exceeding 50 microvolts. This usually results in low radio-noise levels on the power lines. However, additional filtering may be necessary to eliminate resonant peaks. The objection to this method of filtering is the large amount of filter weight required. A source-filter installation on a large military airplane could subtract approximately 100 pounds from the pay load of the airplane.

(*c*). *Compromise Filtering*. This method is a compromise between the two methods discussed above. A limit of 500 or 1,000 microvolts can be specified for each noise source on the airplane. In the case of motors, this level can usually be achieved by the installation of a 0.1- or 0.2-microfarad capacitor across the brushes. The additional filtering is secured by the natural attenuation of the wiring and by capacitors

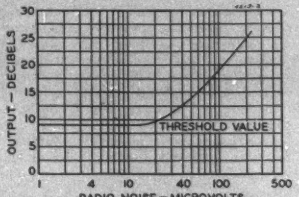

Figure 2. Typical curve of conducted radio noise on the receiver power supply versus receiver noise output for one frequency

340 kilocycles

located in appropriate junction boxes. A comparison between source and compromise filtering is shown by the curves on Figure 4. This test was conducted on a simulated-airplane-wiring network consisting of four motors, a receiver, and a power supply. Curve *A* represents the noise level at the receiver with each motor individually source filtered to a level not exceeding 50 microvolts at the motor. Curve *B* represents the over-all noise level at the receiver with each motor individually source filtered to a level not exceeding 1,000 microvolts at the motor.

Figure 4 indicates that very little advantage is derived from the use of heavy source filters. The 1,000 microvolt limit is not the final recommended value for this type of filtering. A value of 500 microvolts would probably be a more satisfactory compromise. In any event it would be desirable to use a level that could be attained by incorporating a small capacitor into present motor frames without necessitating a redesign of the motor. In designing for this particular type of filtering, space provisions should be allowed in junction boxes for installation of by-pass capacitors. Installations of these capacitors are determined

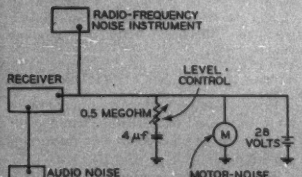

Figure 1. Laboratory setup for determining threshold of conducted radio noise for a receiver

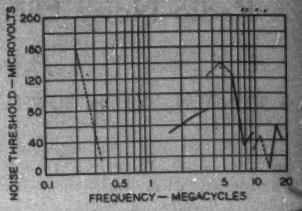

Figure 3. Curve of threshold of conducted radio noise for a receiver

The dash and solid lines indicate successive receiver bands

at the time when the completed systems are tested.

Ignition Radio Noise

The ignition system of the airplane sets up high-intensity radio-frequency induction fields in the vicinity of the airplane antennas. These interfering fields can be decreased by proper shielding of the ignition system. Shielding metal must be of sufficient thickness and high conductivity and each component part of the ignition shielding must be tied by means of low-impedance bonds to each adjacent member and to the airplane structure. Failure to have clean tight mating surfaces between component parts will result in ineffective shielding. On many airplane designs much engine testing is done on test stands prior to the completion of the airplane. If such is the case, an excellent opportunity avails itself to determine the suitability of the engine installation as regards radio noise.

Field-strength noise-instrument measurments can be made approximately ten feet forward of the propeller plane to indicate the severity of the ignition noise and to determine noise peaks. The ignition interference will usually resonate at approximately 9–10 megacycles. Upon determining the resonant frequency of the ignition system, the engine can then be probed to determine the efficiency of the bonding and shielding.

A Ferris model 32*A* noise instrument, or its equivalent, can be used with a probe to obtain a relative measure of the effectiveness of the bonding. A coaxial line of sufficient length and terminated with a sharp steel probe is attached to the Ferris noise instrument antenna input. The sharp point on the probe allows the test engineer to break through protective finishes on the metal in the probing operation. A ten-to-one radio-frequency voltage ratio from the magneto case to the high-voltage conduit would indicate a high-impedance bond between the two units. A high radio-frequency difference of potential between the engine and the airplane nacelle would indicate poor engine bonding.

After the incorporation of necessary

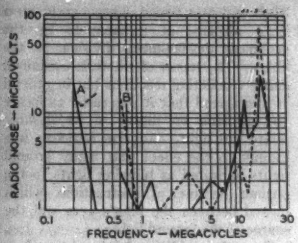

Figure 4. Comparison of source filtering and compromise filtering

A—Source-filtered installation

B—Source-, line-, and receiver-filtered installation

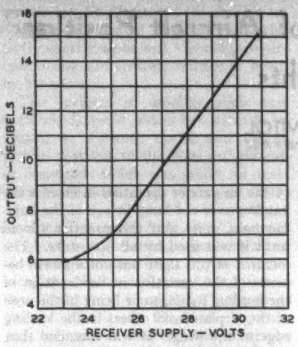

Figure 5. Variation of receiver internal noise with changes in receiver supply voltage

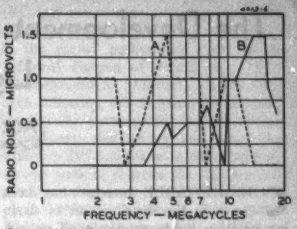

Figure 6. Comparison of the calibrated-receiver and noise-instrument method of measuring noise on an antenna

A—Noise-instrument measurement

B—Calibrated-receiver measurement

bonding and shielding changes, the field-strength measurements are repeated to determine whether additional work is necessary. Experience has not yet determined a satisfactory allowable field-strength level.

By following a procedure as outlined above, necessary changes in the bonding and shielding of the ignition system can be determined prior to the airplane's completion.

Testing the Completed Installation in the Airplane

With knowledge of the allowable conducted radio noise in microvolts for each receiver, compliance with these values can be determined by measurement at the receiver power inputs. This test should be conducted with various combinations of equipment on the airplane operating. The combinations should approximate as closely as possible service conditions. This is extremely important since various combinations of equipment may produce different levels of radio-noise voltage.

Antenna leadins must be carefully checked for radio-noise pickup from the power wiring in the airplane. An indication of the magnitude of this pickup can be determined by listening to the output of the receiver with the antenna leadin disconnected from the feed-through insulator. As a result of this test, re-routing of wiring and further reduction in radio-noise voltage by filtering may be necessary. However, in filtering, care should be exercised against increasing the magnetic-induction radio-noise field by increasing the flow of radio-noise currents. Field-strength measurements should be repeated ten feet forward of each engine and the results compared with the values obtained on the engine test stand. If necessary, further probing on the engine should be accomplished.

Over-all performance of the radio equipment, or the true measure of the effectiveness of the radio-noise design, is determined by the calibrated-receiver method. A receiver of the type to be used in the installation is calibrated in terms of a signal modulated 30 per cent at 400 cycles. Receiver output is measured with a quasi-peak-reading noise instrument of weighting circuit 10 milliseconds charge and 600 milliseconds discharge. Thus each receiver becomes an equivalent radio-frequency noise instrument. This arrangement combines the advantage of a noise instrument with the advantage of testing the actual receiver installation.

Accuracy of the calibrated-receiver method of radio-performance testing is dependent upon the following precautions and calibration technique:

(*a*). The power-supply voltage, both in the laboratory and airplane, must agree within plus or minus one half volt. Figure 5 shows how voltage variations affect the internal noise of a receiver.

(*b*). Circuit constants of the dummy antenna used in the receiver calibration should agree to within 20 per cent with the characteristics of the applicable airplane antenna.

(*c*). A minimum warm-up period of 30 minutes, should be allowed the receiver before any testing or calibration is undertaken.

(*d*). Calibration in the laboratory should be accomplished in a shielded room with a self-contained battery power supply.

By observing these precautions experience shows that results can be duplicated to within one decibel.

Readings of receiver decibel output in the airplane can be converted into equivalent microvolts from the receiver calibration curves. Maximum radio noise at the receiver input has been set by the services at 2.5 microvolts. Experience may permit a reduction in this value at a later date. Figure 6 shows comparative curves of an antenna measurement by the calibrated-receiver method and by a Ferris model 32*A* radio-noise instrument. The readings were taken as nearly simultaneously as possible. The curve of Figure 3 is for the calibrated receiver used in this test. It is interesting to note that the calibrated receiver minimum threshold values of conducted radio noise occurs in the range of 13–15 megacycles. This may explain the peak at 13 megacycles shown by the calibrated receiver in Figure 6. The Ferris instrument readings do not contain the effect of conducted radio noise.

Conclusions

1. It is possible, with knowledge of values of conducted radio noise that can be tolerated at the receiver and from tests conducted on test engines to complete a great deal of preliminary recommendations and designs which will decrease the delay in accomplishing a satisfactory receiver installation on production airplanes. The design, however, must be fluid to permit necessary changes during the tests on the prototype airplane.

2. A compromise system of filtering at source, junction box, and receiver is the most practicable and economical means of accomplishing radio-noise suppression within the fuselage of the airplane.

3. A calibrated-receiver method of evaluating the equivalent microvolts of noise should be the final test of the receiver installation.

4. Studies indicate that noise levels of 500–1,000 microvolts, if specified for electrical equipment installed in the airplane, would permit satisfactory levels of radio noise with a minimum filter weight.

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The Development of Aircraft Position Lights

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CONSIDERABLE interest has been shown in the development of flashing position lights as displayed on air-carrier aircraft at night and this paper is devoted to an explanation of changing trends in aircraft position lighting and the developmental work which finally resulted in the use of these flashing lights.

The need for a uniform system for the display and color of position lights on aircraft was soon demonstrated in the early history of aviation, particularly in Europe, where the proximity of many countries proved the need for uniformity. In October 1919 a convention met in Paris to discuss from an international point of view matters pertaining to aviation, and aircraft position lighting was one of the items which came up for consideration. Without going into any detail, it will suffice to say that it was decided that a red light be displayed on the left wing tip, a green one on the right, and a white light in the tail. The forward lights were to be visible through an angle of 110 degrees measured from dead ahead to the left and right, respectively, for the left and right lights, thus leaving an angle of 140 degrees for the tail light.

In 1926, the Civil Aeronautics Act was passed and when the Aeronautics Branch of the Department of Commerce was subsequently established, the requirements for position lights were drawn up which conformed with the principles as set forth at the Paris convention. Forward and rear lights were required to have a minimum intensity of eight candles and these requirements were in existence for years until the speed and number of aircraft operating at night had increased to the point where additional forward light was desirable, particularly for air-carrier aircraft. Accordingly, Aeronautics Bulletin number 7E as amended in October 1934 required that air-carrier aircraft display at least one stronger light to warn other aircraft of its presence. It was unfortunate that the requirement was so indefinite as it failed to specify the color, location, and the minimum intensity of the light. The result was that some one of the air-carrier operators inserted a 32-candlepower red lamp in one of the landing light units and this practice spread until it was used by all operators. The location of this light was not uniform because of the variation in the location of the landing lights, some being in the nose of the airplane and others in the leading edge of the wing. It was intended that this warning light be burned in conjunction with the forward lights but many of the pilots turned these lights on only when they knew that they were soon to pass an oncoming plane on the airway. The light thus was referred to as the "passing" or "courtesy" light.

The shortcomings of the warning light were soon apparent and in November 1937 the Civil Air Regulations provided for the display of a light on air-carrier aircraft having a minimum beam intensity of 35 candles directly forward. Difficulties in designing a light to meet the cutoff requirements resulted in a revision to the regulations in November 1939 which increased the minimum forward intensity to 40 candles while relaxing somewhat on the cutoff and stray-light requirements. By mid-January 1940, two manufacturers had obtained approval of air-carrier forward position lights and they were being shipped to purchasers. These lights were helpful, of course, but they did not solve the aircraft-lighting problem entirely. Congestion of aircraft over all of the larger airports where air-carrier traffic was predominant, disclosed the need for certain further improvements in aircraft position lighting. Pilots reported that they had some difficulty in locating and identifying aircraft as such which were ahead and below them. In many cases these were small slow aircraft engaged in night training flights. The pilots in overtaking ships claimed that the single white steady tail light on the aircraft ahead became one of thousands of city and airport lights which served as its background. In cases where the red or green wing tip lights were visible rather than the tail light, the lights were not easily picked up because of the number of colored neon lights in the background.

With the feeling that airplane conspicuity should be improved, at least from the rear, the Civil Aeronautics Administration was able to interest a Baltimore inventor in developing a device for flashing the tail light, the theory being that by so doing, it would be more readily discernible. The flasher was ready late in 1940 and was tested subsequently on a CAA airplane at Indianapolis by the technical development division of the CAA. The report of the tests contained many conflicting reactions but in general it was agreed that it was easier to locate the airplane by means of its flashing white tail light. Adverse criticism was mainly to the effect that many ground lights appeared as blinking lights to the airman because of obstructions which passed between the pilot's eyes and the source of the ground lights.

To gather additional information pertaining to the suitability of aircraft position lights, a questionnaire was prepared in July 1941 and sent to air-carrier operators and pilots, operating and engineering managers, and all interested parties. Replies were received from the following, as indicated:

Pilots	217
Engineering managers	5
Operating managers	11
Others	5

Some of the questions and answers were as follows:

1. Do you think the foreward lights (red and green) should be visible from a greater angle to the rear? Yes...(114) No...(106)

2. In your opinion, are the following currently used position lights adequate?

Air-carrier aircraft			
Forward lights	(40 cp)	Yes...(172)	No...(50)
Tail light	(8 cp)	Yes... (60)	No...(154)
Nonair-carrier aircraft			
Forward lights	(8 cp)	Yes...(27)	No...(168)
Tail light	(8 cp)	Yes...(46)	No...(145)

3. If considered inadequate, please describe in what respects.

As may be expected, there was a great variation in the answers but in general they indicated that greater-intensity lights were desired; that the tail light particularly should be brighter; that there should be no difference between light intensities on air-carrier and nonair-carrier aircraft; that all forward lights should have a minimum intensity of 40 candles; and that the tail light should be made more distinctive by the use of a blinker and a different-color light.

The next question is particularly interesting as it indicates to what extent pilots rely on their position lights to aid them while flying at night.

4. To pilots. (1) Do you make muck use of the color arrangement on another airplane to determine its directional path or (2) are you interested only in knowing of its presence?

There were 176 who stated that they made use of the color arrangement to determine an airplane's directional path and there were 70 who were interested only in knowing of its presence. It will be noted that the total number of opinions exceeds the number of replies. This was due to the fact that some of those who replied stated that they were interested in both. They were primarily interested in knowing of the airplane's presence and then they determined

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The views stated in this paper are those of the author and not necessarily those of the Civil Aeronautics Administration.

its path by means of the arrangement of the colored lights.

5. After giving due consideration to the possible need for larger sources of electrical energy, to the resultant increase in weight, and the possible effect on the aerodynamic performance of the airplane, do you have any suggestions as to how to improve the position light or lighting system on aircraft?

The suggestions for improvements were interesting and extremely varied. Many of the pilots mentioned neon, "lumiline," and fluorescent lighting. They suggested that such lighting be used in the wing tips, the trailing edges of both wings, and control surfaces. Some suggested that these lights be of the yellow sodium-vapor type, while others suggested that they be of the blinking type. In general, there was a demand for more light—either higher intensity or more lights—or both. Others wanted two additional lights in the nose of all aircraft. Several frankly stated that the airplane should be "lit up like a Christmas tree" and one felt that it "should stand out like a ferry boat on a river."

By interpretation of the results of the questionnaire, it was obvious that the pilots were generally dissatisfied with the effectiveness of the position lights. They wanted the lights to have a longer range which meant greater intensity and since so many mentioned distinctive lights and the inability to discern the aircraft against a background of city lights, it appeared that an increase in conspicuity was necessary, particularly for the tail light, as well as a more definite means of identifying the light as belonging to an airplane.

How the inability of a pilot to ascertain that a light belonged to a plane was contributary to an accident was forcefully illustrated about this time. A pilot mistook the steady white tail light of another air-carrier plane on the ground as being a boundary light some distance away and he started his take-off run towards the light. After considerable speed had been attained, the pilot became aware that he was about to crash into a plane. He immediately throttled his engines, swerved the airplane, and put his control wheel hard over, thus attempting to lift his wing over the other plane. In this maneuver he was partially successful although he did strike the outer portion of the airplane's wing.

This accident gave additional impetus to the problem of improving the safety of night flying and it was decided:

(1) That some research be undertaken immediately towards giving the tail light greater conspicuity,

(2) That some work be done towards developing a light which would make air-carrier aircraft more discernible from the front.

The need for the latter was particularly acute because of the danger of collison with Army and Navy aircraft, which for military reasons displayed little and sometimes no light. That this hazard was serious can be illustrated by quoting an operator who stated that within a relatively short time he had 178 military aircraft using the airways ordinarily flown by his pilots.

The problem of building some test units which would permit two lights to be flashed at different cycles and eclipse periods was left to the National Bureau of Standards which was ready for tests during the latter half of August 1941. Approximately 20 observers were present and they represented the Air Transport Association of America, a few air-carrier operators, manufacturers of flashing devices, the National Bureau of Standards, the CAA, and the Civil Aeronautics Board. Constant telephonic contact was maintained between the observers and the personnel in control of the lights on the roof of the East Laboratory on the Bureau of Standards grounds. With the equipment as set up, it was possible to vary the frequency from 30 to 40 to 50 cycles per minute and to change the length of the eclipse periods. The observers were approximately six-tenths of a mile away and all were equipped with pad and pencil to record their reactions to the various light flashes.

Using red and white lights which had been determined in some preliminary observations a few nights earlier as having the greatest penetrating power, the result of the evening's work indicated that alternately flashing red and white lights were best when flashed at a frequency of 40 cycles per minute with the following characteristics: 150 degrees white—10 degrees dark; 150 degrees red—50 degrees dark. The longer dark period was found to be necessary in order to make the following white flash appear as such rather than with a pinkish tint. The eye seemed to retain the red image longer than the white with the result that the dark period had to be lengthened until the point was reached when the following white flash no longer had any pinkish cast to it. It was found that even with 21-candlepower lamps in the units, the red flash lacked intensity and it was necessary to use a 32-candlepower lamp. Subsequently, in order to eliminate the need for stocking two tail lamps of different ratings, a 32-candlepower lamp was used in each unit.

With this much accomplished, the manufacturers of flashing devices had some definite requirements on which to base the design of their flashers. While they were engaged in this work, American Airlines played an important part in the development which led to the present scheme of flashing lights. During the last few months of 1941 and the first in 1942, this operator worked closely with the National Bureau of Standards and the CAA in a number of tests trying out various arrangements of steady and flashing lights. One of these tests was conducted at Washington in January 1942 and was witnessed by approximately the same representatives as participated in the earlier preliminary tests at the National Bureau of Standards. Pennsylvania-Central Airlines, which had been following this lighting project with interest by participating in the various preliminary discussions and tests, furnished a *DC*-3 airplane in which the observers rode to observe the relative conspicuity of the American Airlines airplane with and without the various flashing-light combinations. Additional tests were conducted in February while two American Airlines airplanes flew between New York, N. Y. and Hartford, Conn. During a test on February 25, 1942, a flasher was installed which gave the correct number of cycles and eclipse periods. The results convinced the majority of observers that flashing the red and green wing-tip lights simultaneously with the white tail light and the top and bottom white fuselage lights with the red tail light, gave the best results. The tests also led to the final approval by the CAA of a flasher which had been tested for the flashing schedule, satisfactory operation during three hours of vibration, high- and low-temperature effects in the range from plus 55 degrees centigrade to minus 35 degrees centigrade, radio interference, and operation with variation in input voltage. The motor-driven mechanism required about 300 watt-hours of energy per year for its operation and units are now available which can be used on 12- to 16-volt or 24- to 28-volt systems, although the first unit was designed for use on a *DC*-3 which had a 12- to 16-volt system. In appearance the flasher is a cylinder having a maximum diameter of $4^1/_2$ inches and a height of $6^1/_4$ inches. Its weight is two pounds.

With the approval of this flasher, American Airlines proceeded to install this system of six flashing lights in May 1942. The co-operation of the Air Transport Association was obtained in soliciting its members to notify their pilots to observe this system of lights in order to determine their effectiveness. The pilots apparently were impressed because in November 1942 the operations committee of the Air Transport Association voted unanimously to request the CAA that all air-carrier operators be permitted to install the system of six flashing lights. Naturally this reception was gratifying and permission was given with the proviso that it be uniformly adopted by all of the operators. It should be borne in mind that the Civil Air Regulations which had been revised in February 1942 required only that a flashing red and white tail light be displayed and, therefore, the understanding with the operators was strictly on a "gentlemen's agreement" basis. Although the date of effectuation of this requirement had to be postponed several times because of a number of difficulties, progress in completing the

installations was satisfactory considering the circumstances. With the approval of another flasher in August 1942, an additional source was available which expedited the completion of the flasher installations.

By the end of 1942, practically all air-carrier aircraft were flashing three lights on each of the two flasher circuits with each carrying about 5¼ amperes. One circuit operated the standard color scheme, namely, the red and green wing-tip lights and the white tail light, while the other operated the top and bottom white fuselage lights and the red tail light. Not only was aircraft conspicuity greatly improved from the rear but from the front and sides as well and all pilots were impressed with the added sense of security. Apparently the Air Transport Command thought well of the system also because in December 1942 the CAA was informed by one of the flasher manufacturers that his units were being installed in a number of transport and cargo airplanes operated domestically by the Air Transport Command. These aircraft were flying the airways at night and the desire to maintain the high safety standard then in existence dictated that flashing lights should be installed. The value of flashing lights was accorded additional recognition nine months later when a military requirements policy issued by Headquarters, Army Air Forces, authorized the installation of a flasher on six certain types of military aircraft permanently assigned to activities within the continental United States. However, the authorization did not permit the aircraft to be altered to the extent of adding the white tail light and the top and bottom white fuselage lights. Presumably, the aircraft were badly needed and could not be withdrawn from service to enable the additional lights to be installed. At present the Navy is adopting the standard air-carrier system of six flashing lights for use on its domestically operated transport aircraft and it is our understanding that some aircraft are already so equipped.

This entire development has been aimed at maintaining the high standard of safety while flying at night on air-carrier aircraft. However, sight was not lost of the fact that nonair-carrier aircraft engaged in night flying were potentially just as dangerous to each other and to other air-carrier aircraft. From its very inception, the plan contemplated that something be done eventually to add greater conspicuity to privately owned aircraft of all sizes but it was decided that this program would be subordinate to the other. Now that the air-carrier aircraft are provided with adequate position lighting, steps have been taken to initiate something similar for other aircraft. One of the first things required is a simple, cheap, flashing device. The present devices are somewhat in the nature of precision instruments and cost about $95. A material reduction in price will be necessary before the average private flyer can afford a device of this kind. The need for a simple cheap flasher to cost about $15 was brought to the attention of several manufacturers who are now engaged in working on this problem. The unequal dark periods, namely, 10 degrees and 50 degrees, have added some complication and have been responsible, in part, for discarding certain mechanisms which otherwise might have been suitable as considerably cheaper flashing devices. With the thought in mind of simplifying the design problem, it is our intention to experiment with a flasher having both dark periods equal. The important dark period is the one after the red flash, so it is planned to have both eclipses equal to 50 degrees and to decrease the "on" periods from 150 degrees to 130 degrees. The cycle would thus be 130 degrees white—50 degrees dark; 130 degrees red—50 degrees dark. It is not believed a reduction in the "on" periods would be noticeable.

In addition to a cheap, reliable flasher, a single unit housing both the red and white tail lights is necessary before flashing lights will be commonly used on nonair-carrier aircraft. Lack of space on the rudder, the tail post, or tail cone of small airplanes will make it impossible to install two tail lights of the type currently used adjacent to each other. At least one company is known to be working on this project. Eventually it is hoped that nonair-carrier aircraft operating at night will flash as a minimum their wing-tip lights with each flash of the red and white tail lights.

The Civil Air Regulations have been revised recently to permit the flashing of the red and white tail light on nonair-carrier aircraft. Further revisions appear in order to cover similarly the flashing of the wing-tip lights and the top and bottom white fuselage lights. Before this step is taken and because the use of flashing lights appears destined to spread, a number of questions arise which are in need of further study. For instance, the point has been raised that since the red and green wing-tip lights are used to designate the forward left and right quarters, respectively, the introduction of a red light in the tail is unorthodox and may under certain conditions cause confusion. It has also been pointed out by those interested in international agreements that the use of flashing lights and the introduction of red in the tail is contrary to such agreements. Although this has been handled satisfactorily by the operators whose craft engage in foreign operation, by the use of a switch converting the wing tip and white tail lights to steady lights, the subject may warrant some further consideration inasmuch as a long-range policy for aircraft lighting should be considered.

A short questionnaire has been prepared soliciting some information from the air-carrier operators relative to the reaction of their pilots to the flashing lights now that they have been in use for about two years and it is hoped that the information received will indicate if any major changes in aircraft position lighting are necessary.

Since the presentation of this paper, the replies to the above mentioned questionnaire have been received. Fourteen of the 17 domestic air carrier operators have replied, as indicated, to the following four questions which are the most important ones of the questionnaire:

1. Are you satisfied with the present scheme of flashing the two wing tip lights and the tail light on one side of the flasher circuit and the top and bottom white fuselage lights with the red tail light on the other? Yes 14; no 0.

2. The aircraft's progress with such lights flashing has been described by a few as being "jumpy." Is this a serious objection to your pilot personnel? Yes 0; no 14.

3. Does the red light in the tail of an aircraft confuse your pilots as to its direction to an objectionable extent? Yes 2; no 12.

4. Do your pilots think the forward red and green lights should have more intensity? Yes 3; no 11.

On the basis of the replies, it is obvious that the operators as a whole are well satisfied with the present scheme of flashing lights. No changes are thus contemplated, although it is felt that the volume of air traffic in the not too far distant future will force a revision in aircraft position lighting. Such a revision will call for a pattern of flashing lights enabling a pilot to distinguish more readily the quarter from which he is approaching another aircraft.

Electric Gun Turrets for Aircraft

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THIS war has seen an unprecedented development of armament, both offensive and defensive, for military aircraft. One of the most widely used and, therefore, perhaps one of the most important of these has been the power-driven gun turret, three or four of which are used on all our heavy bombers, and one or more on most smaller bombers and equivalent planes. This paper briefly surveys the field of electric-drive equipment for turrets to give a picture of the types and variety of equipment now in use and the requirements made of it, together with a description of how it works.

General Description of Turrets

Basically a turret is a power-driven flexible gun mount. In most turrets now in use the gunner is located within the turret, and by suitable controlling means drives it at any desired speed in rotation about horizontal and vertical axes so as to point the guns continually at his moving target. The gunner actually rides around with the guns and aims by peering through a sight attached to them.

In this connection it would be well to mention the two most prevalent basic types of turret arrangement. These are, first, the cylindrical turret wherein the complete turret with operator, ammunition, and so forth revolves only about a vertical axis, the guns alone being pivoted about a horizontal axis in the turret for elevation and depression. The gunner has to move his head up and down to follow the sight in elevation. The other type is the spherical turret where the gunner is at all times in a fixed position with respect to the guns, and rides up and down with them in elevation as well as around in azimuth. In both cases transparent Plexiglas enclosures through which the guns protrude are used to shield the gunner from the slipstream. Turrets of both types have been applied variously in nose and tail installations, as upper deck turrets, forward and rear, and as lower turrets projecting from the bottom of the airplane fuselage.

Much of the basic turret development was done prior to or in the early days of the war, being pioneered to a considerable extent by the British who concentrated on the caliber-0.30 automatic machine guns and used them in multiple gun installations, usually numbering four guns. American turrets from the first have used the caliber-0.50 machine gun in arrays of from one to four. By far the greatest majority, however, have had two guns, one on either side of the gunner. Larger caliber armament including 20-millimeter and 37-millimeter cannon has been used, but mostly experimentally to date.

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Power-Drive Requirements

The necessity for power drives in aerial gunnery is immediately apparent from the desire for high fire power which demands more, larger, and heavier guns, and from the forces imposed on the guns by the wind velocities encountered with modern high-speed airplanes. Wind loadings on a twin caliber-0.50 turret for a modern bomber have been checked at between 300 and 400 foot-pounds of torque, varying roughly sinusoidally as the turret is rotated through 360 degrees. In addition, such a turret with full complement of ammunition, armor plate, and accessories may weigh in the neighborhood of 700 to 1,000 pounds, which must be accelerated quickly to meet the requirements of aerial combat. The top speed generally required of aircraft turrets is about 10 rpm, which represents a figure somewhat over 0.5 horsepower. Larger guns take up to 1 or 1.5 horsepower. Obviously, a human gunner could not maneuver the guns to any reasonable degree without the aid of a power drive.

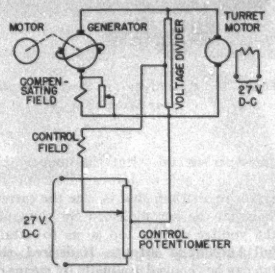

Figure 1. Basic Amplidyne control circuit

The requirements for a turret drive are quite stringent. The guns must be under perfect control at all times if accurate shooting is to be accomplished, and no looseness in the response to the controls is to be tolerated. Perfectly smooth steady operation must be obtained over the entire speed range from zero to the top speed of the turret, and the turret speed should be as insensitive as possible to the changes in wind loading when it revolves. High accelerations and quick reversals must be obtainable, and the equipment must be light, simple, trouble-free, and easy to maintain. In addition, it must perform equally as well at altitudes of 40,000 feet and ambient temperatures of −65 degrees Fahrenheit as it does under normal conditions or under conditions of desert heat. Of course it must withstand the shocks and vibrations incident to use on military aircraft.

Types of Drive Equipment

Both hydraulic and electric-power-drive systems have been used successfully for turrets. The hydraulic drive was long favored because of the smoothness and slow speeds which were obtainable, and in more powerful designs because of its light weight. However, control difficulties, problems of leakage, cold weather troubles, and vulnerability have militated against it to an appreciable extent. At the present time, in this country at least, hydraulic turrets are in the minority.

The wide range of load and speed required makes an unusual control problem for aircraft electrical equipment. To date the most successful solution to it has been use of the Amplidyne type of generator, and by far the greatest majority of electric turrets are now Amplidyne controlled. The Amplidyne is especially suited for turret control because of its quick response and high power amplification. These features permit accurate control and the use of a very small amount of control power, which means the utmost in small and simple control devices.

Amplidyne Control Circuit

Figure 1 illustrates the circuit in general use with Amplidyne turret drives for controlling the speed of the turret-drive motor. It is fundamentally a variable-voltage system with negative-voltage feedback for regulation and stability. The controlling means is a center-tapped

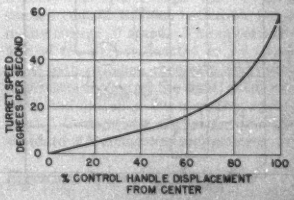

Figure 2. Typical speed-response curve for a turret

potentiometer fed from the airplane's 27-volt d-c supply, and exciting the low-wattage control field of the Amplidyne. Turret motor speed is controlled by varying the magnitude and polarity of the Amplidyne field excitation. The turret motor is a separately excited shunt machine, so it is necessary to compensate the Amplidyne (by means of a series field) somewhat over 100 per cent to overcome *IR* drop and inherent speed regulation of the motor, and thereby maintain good turret speed regulation under high loads. Such a system would be unstable by itself at lower speeds and loads, and so a portion of the Amplidyne output voltage is fed back into the control field circuit for stabilization. This is obtained from a resistor which constitutes a voltage divider across the Amplidyne output. The field excitation is the difference between the potentiometer output and the voltage from this divider. The position of the divider tap determines the Amplidyne output voltage for any control potentiometer setting, making this in effect a speed regulator circuit. With a linear control potentiometer the turret speed characteristic, with respect to control handle displacement, is a straight line. This is quite positive and gives both high acceleration of the turret in response to the control handles and a dynamic braking effect for holding the turret steady against the wind, even when the control potentiometers are not energized.

With the machines commonly in use this circuit has a time constant of response of about 0.04 second and can accelerate a turret up to 500 degrees per second per second. Because of the high inertias involved at such accelerations, it is necessary to antihunt the system. To accomplish this an additional field is connected across the Amplidyne output through a capacitor and is of such polarity as to buck down any voltage produced by the control field. This arrangement merely prevents an oversensitive Amplidyne from accelerating the turret too fast.

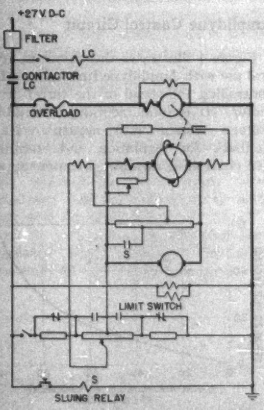

Figure 3. Typical turret-drive elementary diagram

Sluing Circuits for Amplidyne Control

The basic circuit described previously is readily adaptable to modification by several types of additional control and safeguard circuits useful in turrets. One of the most important of these is a sluing circuit, which amounts to a gear shift for tracking speeds. When tracking a target the gunner seldom needs to operate the turret at a high rate of speed, and it is not desirable to have too great a change in rate for a given motion of the control handles, as this makes control more difficult. For tracking, a voltage divider tap is used which gives a maximum turret speed of 20 or 30 degrees per second. But the gunner also wants to be able to shift rapidly from one target to another, that is, slue the turret. This can be accomplished by changing the voltage divider tap so as to obtain full Amplidyne output. If desired, the tap can be changed gradually by means of another potentiometer geared to the control handles so as to change the slope of the response curve gradually, as shown in Figure 2.

Figure 4. Amplidyne for turret drive and speed control

Limit Circuits for Amplidyne Control

In addition, a limit circuit is often desirable to prevent the gunner from running the guns down full speed into the side of the airplane. Such a circuit must have an automatic backout feature, and it must be simple. It is accomplished easily by having a limit switch short circuit that side of the control potentiometer which drives the guns toward the limit.

Miscellaneous Circuit Modifications

Generally an "action switch" or "deadman" is incorporated in the control handle to cut off power from the control potentiometers when the handle is released. This is a safety feature to prevent the turret from swinging around in the event that the controls should be knocked accidentally when power is connected to the turret.

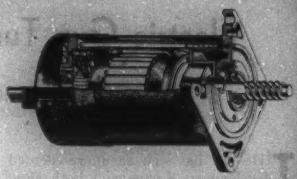

Figure 5. Sectional view of typical turret motor showing brake coil and mechanism near pulley end

It often is considered desirable to have brakes on the turret to prevent its swinging around in the wind when power is off. A nonreversible worm drive would accomplish the same thing but is rather inefficient. For this purpose some turret motors have brakes built into them, which release magnetically when power is applied to the field.

Figure 3 shows a typical turret control circuit elementary for the elevation motion. The Amplidyne is driven by a compound-wound motor directly off the ship's 27-volt d-c supply. It is started by a relay, has thermal overload protection, and there is generally a radio-noise filter in the line. The turret motor field and brake are energized at the same time the Amplidyne is started, so as to prevent circulating currents flowing around the loop circuit between generator and motor armatures. The control potentiometer is energized by a separate "action switch," and sluing is obtained by means of a relay. Upper and lower limit switches with current-limiting resistors are included. Miscellaneous accessories are not shown.

Turret Amplidynes

The Amplidynes now in general use are two-bearing motor generator sets 12 inches long and 29 pounds in weight (see Figure 4). The motor is compound-wound with eight poles, rated at 27 volts and 44 amperes direct current. It runs in ball bearings at 8,300 rpm. The generator is rated at 60 volts, 8.8 amperes (530 watts) for ten minutes, and at this output requires about 60 milliamperes in the 25-ohm control field (0.1 watt). These machines also have a $1^1/_2$ minute rating of 750 watts, corresponding to the maximum wind load torques on the turret, and will put out over 1,000 watts for short times, necessary for breaking away a frozen or iced-up turret. Because it is expected that they will not have long life in such an application, the temperature rise generally is considered to be limited by what the commutators will stand before throwing solder. All connections are made

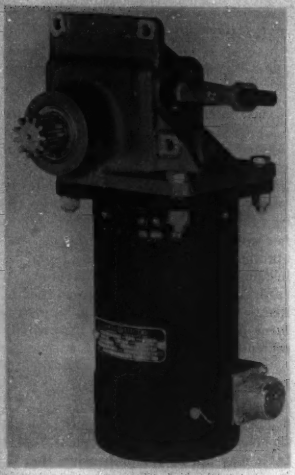

Figure 6. Turret motor and gearbox showing pinion to mesh with turret-ring gear and lever to declutch motor

Gear reduction: 10 to 1

through a single *AN* connector, and two rheostats are mounted on the side for shunt adjustment of the compensating field. A fan is located on the motor end of the machine, and all rotating parts are balanced dynamically. Vibration is quite important insofar as it affects generator commutation, which is extremely critical for smooth turret operation and correct compensation. Special brushes are used for satisfactory life at high altitudes, consistent with reasonable commutator and brush life at sea level.

Turret Drive Motors

The drive motors for the turrets are rated at 60 volts armature and 27 volts field, and generally are rated at 4,000 rpm. Good performance is required, however, over the entire speed range and particularly at very low speeds. Sticky bearings or any tendency for slot-locking will give ragged turret performance at the lowest speeds where accurate aim is usually most important. The motors must be able to take whatever the Amplidynes can put out, and this often may mean almost instantaneous reversal of maximum applied armature voltage. Of course they must run equally well in both directions, and the maximum speeds in opposite directions should be essentially equal. When space permits they are supplied with a fan for cooling, but its value is questionable, as the motors must run at low speeds and full torque for much of the time. A typical turret motor is shown in Figure 5. It is seven inches long and weighs about ten pounds. Its ten-minute rating is 0.5 horsepower at rated voltage and 8.3 amperes. Figure 6 shows a similar motor mounted to a gear reduction box for driving a turret. Note that a lever is provided to declutch the worm-drive gearing to make the turret easier to rotate manually in the event of power failure. The over-all efficiency of a drive system using such motors and Amplidynes is in the neighborhood of 40 per cent (not including turret gear efficiencies).

Control Units for Turrets

Satisfactory control equipment for easy, efficient, and accurate manipulation of the guns requires a carefully designed control unit. The controls above all must be simple and "natural;" that is, their arrangement must be such that their correct operation is virtually instinctive, with as little as possible for the operator to learn. They must be operable with the minimum expenditure of thought and energy on the part of the gunner, and they must be comfortable and easy to use. When it is considered that the gunner may have to operate the turret for many hours on end, often under conditions of extreme temperature and altitude, it is understandable that much consideration must be given to the ease and comfort of his work if his efficiency is to be maintained.

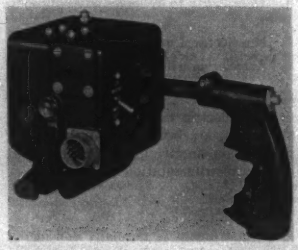

Figure 7. Joy-stick-type control unit for spherical turret

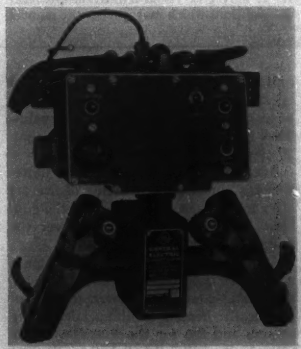

Figure 8. Typical turret control unit with standardized grip arrangement

Many types of control handle arrangements have been tried. Steering wheels, single or double joy-sticks, rotating grips as on a motorcycle, and various types of handle-bar arrangements all have been used. There is no doubt that operation of most any arrangement can be learned, and also that different turret arrangements may require different control arrangements. Figures 7 and 8 illustrate two typical control units, one a joy-stick type with pistol grip, and the other a double-grip arrangement. The former has been quite satisfactory in a spherical-type turret. For cylindrical turrets the double-grip arrangement of Figure 8 has been found most satisfactory, and it has been standardized wherever possible. In this arrangement both grips move together and rotate on a horizontal shaft for elevation control and about a vertical axis midway between them for control of azimuth rotation. The two grips customarily are placed close together so as to be operated primarily by wrist motion, so as to minimize fatigue. Likewise, friction and inertia should be low, and any spring centering kept very light. However, there still must be enough friction and inertia to give the operator something substantial to hold onto, when the airplane bounces or maneuvers, without upsetting his degree of control. The inertia of the operator's arms and body is important here in creating a control system which is not subject to jerking during acceleration.

In this typical control unit the grips are of plastic material. Each grip has a lever on the side which, when depressed by the weight of the gunner's hand, energizes the control circuit. There is also a gun-firing trigger switch on each grip, operated by the forefinger, and a push button accessible to the thumb for sluing, or for an interphone if desired. The grips can rotate $22\frac{1}{2}$ degrees either side of the center position for both elevation and azimuth control and are geared directly to the control potentiometers. The latter are of sufficient diameter and close-wound with fine enough wire to give smooth control without noticeable steps in the change of speed. The upper portion of the unit is devoted to a control panel with switches, rheostats, and overload resets to control the sight, firing circuits, and miscellaneous accessory equipment. Connections are made through standard *AN* connectors and fittings.

Electrical Accessory Equipment

The electrical gun-firing and accessory equipment being used on turrets nowa-

Influence of Electricity on Aircraft Instrumentation

C. F. SAVAGE
MEMBER AIEE

Synopsis: Many factors have operated to set up conditions which have been very favorable to the electrification of aircraft instrumentation. Two tabulations are presented to indicate the extent to which electrical principles have been applied to common aircraft instruments. The effects of increased size in aircraft, larger power plants, longer flight time, association with other equipment, and other factors upon instruments are discussed. The advantages of electric instruments are presented, and some possible future developments are noted.

CURRENT bibliographies on aircraft instruments list a reference to an early article dated 1904—40 years ago. This paper, describing an altimeter, has been followed by thousands more indicating the interest and technical advancements in aircraft instruments. The needs of the aircraft industry have been met by the instrument manufacturers. Developments in instruments have paralleled the rapid developments in aircraft due to the close co-operation of measurement and aeronautical engineers. A typical aircraft instrument panel is shown in Figure 1.

Since few manufacturers make a complete line of aircraft instruments, an overall listing of the devices included in this field is difficult to find. Textbooks, bulletins, and trade catalogues list instruments under various classifications. The devices covered and the typing are seemingly influenced by popular terminology and the author's particular interest. Another classification is not, then, out of order.

Aircraft instruments can be identified by the function which they perform. A tabulation made on this basis should be of interest in cross-checking the needs of the aircraft with the instruments available. Aircraft instruments can be grouped by the type of instrument and by the basic principle of operation.

Because many factors have operated to set up conditions which have been very favorable to the electrification of aircraft instrumentation, particular emphasis can be placed on this effect by segregating the electric instruments from other types.

The increase in use of electric instruments is traceable to the following factors:

1. Increase in size of aircraft.
2. Increase in size of power plants.
3. Longer flight time.
4. Desirability to fly under adverse conditions.
5. Nonelectrical methods not feasible.
6. Association with other equipment.
7. Adaptability to available power source.

Since electric devices, other than instruments, are being used in increasing numbers on aircraft, it is anticipated that electric instrumentation will progress.

Scope

An instrument is normally considered a measuring device. In the control of any process, regardless of its nature, a measuring device may function in two ways:[1]

1. It may give visual indication of events or conditions which may govern the manual adjustment of apparatus controlling these events or conditions.
2. It may initiate actions which automatically adjust equipment controlling events or conditions.

Only instruments in the first group are considered, since control devices such as voltage regulators, fuses, and speed-control apparatus are included in the second group. The aircraft industry operates in general within this definition. Two exceptions are warning lights, which are not considered to be instruments, and automatic pilots, which are classed as instruments. Interlocking operation, so easily accomplished by electrical means, makes the distinction between an instrument and a control device increasingly difficult.

Classification

Table I shows aircraft instruments by basic type of measurement. This table may not be comprehensive, that is, it may not include all instruments, but it does show all instruments used in any quantity. Automatic pilots are not tabulated, since their function other than control is duplicated by other gyro instruments.

Table II shows the aircraft instruments segregated into their classes: flight, navigational, engine, and miscellaneous with the basic principle of operation listed. Further classification is made by dividing the instruments into groups indicating that the instruments operate as self-contained units or consist of two units, a transmitter and a receiver, to give remote indication. The means by which the basic principle of operation is effected is also shown.

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days has reached considerable proportions. Guns are fired almost without exception by electric solenoid devices mounted on the guns, and drawing from four to eight amperes. Usually both guns are fired simultaneously, although sometimes provision is made for separate firing of the guns when desired. Cam-operated fire interrupter switches are used in these circuits to cut out the gun fire in interference regions, so that gunners will not inadvertently shoot away the tail or wings of their own airplane.

Because of the large amounts of ammunition carried, the feeds to the guns are long and tortuous, so that ammunition boosters are required. These are ratcheted sprockets powered by small intermittently rated electric motors which operate when tension in the ammunition belt reaches a predetermined value. They generally take considerable current; 20 amperes is not unusual.

Automatic electrically driven movie cameras aimed along the line of fire are often used to record the effect of the gunfire. They are energized whenever the firing trigger switches are closed.

Additional electrical accessory equipment often used includes the interphone, a rheostat-controlled power outlet for electrically heated clothing, defrosting heaters and fan for the Plexiglas dome, and usually a "trouble light" on the end of a flexible cord for general illumination.

The total power drain of a 27-volt turret with everything running at once, and going at full speed against the wind may be well in the neighborhood of 175 amperes.

Conclusion

Amplidyne turret drive and control equipment is now in use on thousands of turrets of several different types and manufacture all over the world. It lends itself readily to many control-circuit variations and mechanical arrangements and is eminently simple and easy to service and maintain. All reports have indicated that it is thoroughly reliable and performs its proper functions satisfactorily.

Figure 1. Typical aircraft instrument panel

There are some measurements, such as exhaust-gas analysis, which are made only by electrical means. Some measurements, such as time, are made only by mechanical devices.

It is indicated that many measurements can be made by devices utilizing both mechanical and electrical principles in their operation. While certain instruments, fuel-quantity gauges, for example, can be obtained operating on more than one principle, general usage is in favor of those utilizing electrical means. Figure 2 shows the relative quantity of instruments available in the various classifications.

Factors Favoring Electric Instrumentation

Airplane Size

The size of aircraft has increased tremendously. Wing spreads over 200 feet are not uncommon. Engines are placed out on the wings with the obvious result that engine instruments are principally electrical in operation or utilize electric transmission. Electric tachometers eliminate the impossible task of using flexible cable drive through a distance of as much as 60 feet between the engine and the instrument panel. The saving in weight by eliminating the use of cable is many pounds. Synchronization of multiple engines is indicated easily by electric synchroscopes operating from tachometer generators.

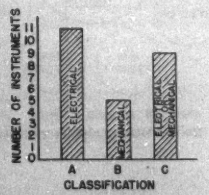

Figure 2. Summary showing relative quantity of instruments in various classifications

Many pressure indicating devices utilize electrical transmission to eliminate long heavy pipe lines, thus reducing installation costs, maintenance difficulties, and operational hazards by avoiding the danger of leaks and by decreasing vulnerability to gunfire.

Other parts of the airplane are often so far from instrument or control panels that the electrical method is the only practical means of measurement. Gasoline tanks are multiple in number and placed in all parts of the airplane. Landing gear, flaps, and so forth cannot be seen by the pilot, and position indication must be provided.

Remote-indicating electrical compasses[2,3] are a necessity because of the impossibility of maintaining a uniform magnetic field in the cockpit. The pickup element must be located in a remote position, such as the tail or wing, to secure accurate readings.

Much has been written on the subject of power systems in aircraft. Increased power loads and the use of 400-cycle supply dictates the use of ammeters, voltmeters, wattmeters, and so forth, to assure proper control.

Table I. Classification of Aircraft Instruments

	Specific Measurements	Instruments
1. Measurement of Quantity		
Absolute — Solids, liquids, gases	Fuel quantity	Flowmeter
	Airplane height	Radio altimeter
	Ice accumulation	Rate-of-ice-accumulation indicator
Absolute — Electricity	Electric load	Ammeter
With respect to time — Power — Mechanical	Engine horsepower	Horsepower indicator
With respect to time — Power — Electrical	Generator load	Wattmeter
2. Measurement of Quality		
Composition analysis	Fuel mixture	Exhaust-gas analyzer
3. Measurement of Condition		
Temperature	Outside air, Oil, Coolant, Carburetor mixture, Inside air	Thermometer
	Engine cylinder, Jet exhaust	Thermocouple
Pressure	Oil, Fuel, Manifold, Suction, Deicing equipment	Pressure gauge
Speed	Engine rpm	Tachometer
	Engine synchronism	Synchroscope
	Airplane rotation	Rate of turn indicator
	Airplane acceleration	Accelerometer
	Electrical frequency	Frequency meter
	Airplane forward speed	Air-speed indicator
Potential	Electric potential	Voltmeter
Displacement	Oil quantity, Fuel quantity	Liquid-level gauge
	Wheel position, Flap position, Oil-cooler flap position, Cowl flap position	Position indicator
In space	Level flight	Gyro-flight indicator
	Direction	Directional gyro, compass
	Weight	Altimeter
	Change in height	Rate-of-climb indicator
	Pitch angle	Inclinometer
	Stall conditions	Stall indicator
In time	Drift	Driftmeter
	Time	Clock

Power Plants

As the size of aircraft engines has increased, the necessity for improved control has been noted. Carburetor air temperature requires a sensitive measuring device capable of following quickly any change in temperature. The resistance bulb and ratio-type temperature indicator fills this need. Improved cylinder-head temperature indicators are being developed to permit engines to be operated at higher efficiency. The position of cowl flaps and oil-cooler flaps is indicated by electric instruments.

The very high temperatures encountered in jet-propulsion engines are being measured by thermocouples which constitute the only practical means.

Longer flights dictate rigid maintenance to flight schedules and the attainment of high efficiency in operation. Fuel flowmeters, utilizing electrical transmission, are standard equipment. New and improved horsepower indicators[4] aid in obtaining efficient engine performance.

Flight Conditions

Airplane performance has been improved, so that flights are made under extreme conditions of weather, altitude, and temperature. Electric instruments aid by providing not only good performance in general under these conditions, but also provide some specialized indications. Rate-of-ice-accumulation instruments are electronically operated. Pressurized cabins for high-altitude flight present difficult problems in that the tubing and other connections for mechanically operated instruments must be sealed at the point of cabin entry. Airtight electric connections are made easily by gasketed lead-in studs.

Limited Methods

Certain measurements are made by one type of instrument because no other method appears practical. Clocks will

Table II. Operating Principles of Aircraft Instruments

	Self-Contained				Remote Indicating				
Class—Instrument	Electrical	Mechanical	Mechanical-Electrical	Mechanical-Pneumatic	Electrical	Mechanical	Mechanical-Electrical	Mechanical-Hydraulic	Mechanical-Pneumatic
Flight Instruments									
Altimeter		Aneroid							
Rate of climb		Manometer							
Air speed									Manometer
Free-air temperature					Resistance measurement			Pressure gauge	
Accelerometer		Mass measurement							
Inclinometer		Pendulum							
Flight indicator			Gyroscope	Gyroscope					
Rate of turn indicator			Gyroscope	Gyroscope					
Stall indicator			Pressure switch						
Navigational Instruments									
Directional gyroscope			Gyroscope	Gyroscope					
Compass		Compass			Magnetic saturation		Compass-magnetic saturation		
Clock		Escapement							
Driftmeter			Telescope						
Engine Instruments									
Pressure indicators							Pressure gauge—electric transmission	Pressure gauge—hydraulic transmission	
Temperature indicators		Bimetal			Resistance measurement and thermocouples			Pressure gauge	
Tachometer					Magnetic-drag electric transmission	Magnetic-drag machine coupling			
Synchroscope					Frequency comparison				
Fuel and oil-quantity gauge		Sight-gauge and float type					Float level—electric transmission	Float level—hydraulic transmission	
Flowmeter		Volumetric pump					Volumetric pump; Pressure measurement; Velocity measurement (Electric transmission)		
Horsepower indicator							Combined torque and speed indicator		
Exhaust—gas analyzer					Thermal conductivity—resistance measurement				
Miscellaneous Instruments									
Position indicators					Resistance measurement				
Ammeter	Direct current—permanent-magnet moving coil								
Voltmeters	Alternating current—moving-iron vane								
Wattmeters	Electrodynamic								
Frequency meters	Series resonance								
Ice accumulation					Capacitance measurement				

Figure 3. Components of an electric–hydraulic automatic pilot

continue to be mechanical until better regulated electric power sources are available. Exhaust-gas analyzers and distant reading compasses have been mentioned previously. Radio altimeters are the only instruments available for obtaining absolute height above ground. It is expected that instruments operating entirely on electrical principles will assist in obtaining better fuel quantity measurements.

Associated Equipment

Electric instrumentation is easily adapted to meet requirements calling for the combination of two or more measurements or of measurement and control functions. The horsepower indicator combines engine torque and speed. The electric tachometer and synchroscope work as a team. Electric compasses are used to control the precession of directional gyroscopes. Moreover, the remote totalization of several measurements can be effected easily to determine, for example, the total quantity of fuel in a number of separate tanks.[5]

Electric gyroscopes, as used in automatic pilots, are outstanding examples of combined instrumentation and control. Figure 3 illustrates the components of an electric–hydraulic automatic pilot. The electrically operated gyro instruments[6] incorporate electric pickoffs which give the required signal for automatic pilot control. The operation of the flight indicator and the directional gyroscope as indicating instruments is not impaired, since the signal power required is negligible. Electronic amplifiers provide means for obtaining any power step-up required. Figure 4 identifies the functions which can be controlled by electric pilot instruments.

Other examples of associated instrumentation and control are overspeed control of turbosuperchargers which utilizes the tachometer generator, combining positioning motors and position transmitters, and automatic propeller synchronization.

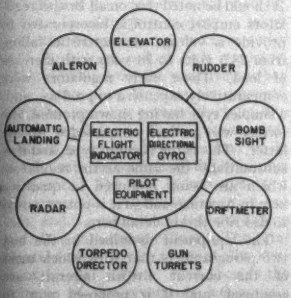

Figure 4. Possible airplane functions controlled by electric automatic pilots

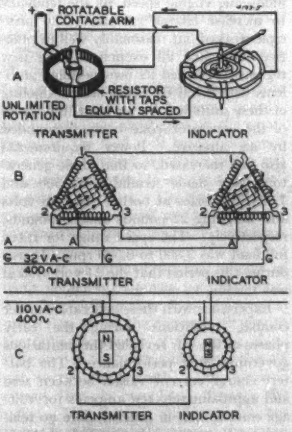

Figure 5. Typical circuit

A. D-c remote indication
B. A-c remote indication
C. A-c remote indication—induced second-harmonic system

Adaptability to Power Source

Many instruments are available in forms to operate from d-c or a-c power sources. In addition, inverters, converters, and rectifiers can be used so that electrical instruments are applicable regardless of the electric system of the airplane.[7] Figure 5 illustrates circuits commonly used for remote transmission of aircraft measurements.

Conclusion

A review of the common aircraft instruments indicates that many operate only on electrical principles and that electric transmission for remote indication has been applied extensively to others. A few instruments cannot be improved by the use of electricity because of their inherent principles of operation or method of application, and these, no doubt, will continue to be mechanical.

Many factors have influenced the electrification of aircraft instruments. Because of the work done, the instrument needs of the aircraft manufacturer have been met, and many new instruments having superior characteristics have been developed. It is anticipated that technical improvement in aircraft instrumentation will continue, and that the benefits obtained from the use of electricity in this field will increase.

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Brief Survey of Power-Supply Developments on British Aircraft

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THIS paper covers the development in broad outline of electric generating equipment and systems on British aircraft from the 1920's up to the present time. The coverage, of necessity, must be very sketchy, but it is hoped that outlining British development in its approximate chronological order may be helpful in comparison with American development over the same period. No attempt will be made to go into great detail, and so pictures and curves have been omitted.

D-C Power Supplies

Early airplanes, which were mostly of the biplane type, used exclusively the so-called 12-volt d-c system. Power was supplied by a "windmill"-driven generator of 14 volts 500 watts capacity. "Windmill" is the British word for the wooden or metal propeller which was actuated by the slip stream of the aircraft, thus rotating the generator armature at its rated speed of approximately 5,000 rpm at the normal cruising speed of the airplane. Various "windmills" of differing pitch were available to take care of the various aircraft which had naturally differing cruising speeds. The generator was built in streamlined form and was mounted usually on the wing. Connection was made at the rear end by a plug and socket, and the weight of the complete assembly was about 20 pounds. Cooling was, of course, by the slip stream and care had to be exercised not to load up the generator to its maximum capacity when running up on the ground for test purposes; 40 per cent full load was the specified safe limit under these conditions unless an air blast was available.

Voltage control of these generators was achieved by a vibrating reed or Tirrill regulator, and also in the same box was located the reverse-current relay. It is worthy of note that these early regulators were screened in a metal box to minimize radio interference and the connecting cable was screened for the same purpose. Round about 1935, research and development were accelerated for obvious reasons which need not be discussed here, and about that time the airplanes which were destined to be our mainstays during the early part of the war were in various stages of development or production. These were the Spitfire and Hurricane fighters and the Whitley, Wellington, Hampden, and Blenheim bombers. All of these were fitted with a new type of engine-driven generator with self-regulating characteristics, which had been developed. The adoption of this generator, by rendering an external voltage regulator unnecessary, solved troubles which had been experienced with Tirrill regulators, the most bothersome of which had been radio interference.

It may be of interest to describe this generator in some detail. Three field windings were provided, a shunt winding for the primary excitation, a series winding to compensate for voltage drop in the generator due to load and thirdly, a control winding. This latter winding was arranged to carry battery-charge current only, and the resultant field was in such a direction as to check rising voltage with increasing engine speed, by the tendency to increase charge current. The principle worked out reasonably well in practice, but, like all excursions into new regions, it created its own peculiar problems which will be noted later. Cooling of these units was by air blast, the whole of the generator yoke being surrounded by an airspace. Power requirements also had increased, so that these generators were made available in 500 and 1,000 watt sizes at both 14 and 28 volts and weighing 22 pounds and 36 pounds, respectively. The speed range for rated full load was 3,000 to 5,500 rpm. It was during this period that the 24-volt system was tending to oust the 12-volt.

Experience with these generators under combat conditions during the early phases of the war revealed the limitations governing their performance. The battery-charge current varied between zero and approximately ten amperes for voltage control and, in general, bore no relation to the state of charge of the battery itself. Thus, if a battery were discharged by ground tests and repeated engine starting, the battery could not accept a heavy recharging current during flight, and undercharged batteries, useless in a crisis, resulted. Further a fixed resistance, switched into the field circuit by the engineer when the voltage reached 14.5 volts, had been found necessary, but this needed vigilance and was therefore undesirable. Another undesirable feature was that a resistance had to be substituted for the battery when the latter was removed from the airplane; otherwise the generator was uncontrolled if the engine was run up. Lastly the voltage characteristics were not stable enough to allow paralleling, and this last problem rapidly was becoming important.

The power-supply policy therefore swung back to shunt-wound generators with external voltage control, and the movement was accelerated by the development of carbon-pile voltage regulators. The generators were built primarily for 24-volt systems but 14-volt units were made available in the 500-watt size for incorporation in later Spitfire and Hurricane aircraft. The speed range remained the same, and it is worth noting here that differing speed range, mounting pads, and drive shafts are the chief stumbling blocks to standardization between American and British units. A new unit of 1,500-watt capacity was added to the range, this being entirely due to improvements to the existing 1,000-watt model.

A brief history of British development of the carbon-pile voltage regulator for aircraft use may be of interest here. The principle is, of course, not new. The first model to go into production differed widely from the type now in general use, and in some aspects this early regulator possessed definite advantages over the now standard model. The pile was exposed and not enclosed in a ceramic tube, and the compression on the carbon stack was effected through a link system giving longer travels which were more easily controllable. The magnet system consisted of a specially shaped armature rotating on ball bearings between the magnet pole shoes, and a dashpot with a graphite piston was provided for damping to prevent hunting. Temperature compensation was provided by an Invar rod. It should be noted that on all British regulators current control is incorporated to provide a voltage characteristic falling from 28.5 volts to 26 volts with increase of load. These early regulators were comparatively expensive to produce, and, a simpler type having shown promise, the former was gradually superseded by the latter. This is the Newton type, and it is substantially the same as the regulators which are being produced in quantity here in America, and so it is not proposed to describe this in detail here.

The equipment described in the last two paragraphs is that with which most of the current British aircraft are equipped, and it is proposed now to sketch briefly present developments in the d-c field; the position regarding a-c development will be treated separately and discussed later. Two generators will soon be in production, one of 3,000 watts capacity and the second of 6,000 watts. By a curious coincidence they

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are types *O* and *P*, and thus they correspond in output to American units of similar nomenclature. The weights are 50 pounds and 55 pounds respectively, but it is believed that an improved 3,000-watt model is under development weighing 35 pounds. These figures compare unfavorably with the American designs, but it must be remembered that the speed range remains 3,000 to 5,500 rpm, and also that the rated output is given continuously.

Voltage regulators have been improved in detail, and the most important change has been to provide two carbon stacks in series in the one regulator, one for voltage control and the other to act as a current limiter instead of the voltage coil and current coil operating on one stack. On single-generator installations the voltage control keeps the voltage constant up to the rated output of the machine, and then the current limiter comes into operation to drop the voltage sharply. In multi-engine aircraft where generators are paralleled, each regulator gives a falling voltage characteristic with load until full load on each generator is reached, after which the current limiters act as before. In addition the load current is taken through a small coil acting on the voltage pile to reduce the voltage of the generator if it tends to take more than its share of the combined load.

Experiment and research are going forward with the paralleling of four of these larger 6,000-watt units in order to get stable installations. The scheme showing most promise incorporates a fifth master regulator which is actuated by the bus-bar voltage to keep this substantially constant, irrespective of the voltage tendencies of the individual generators feeding the system. As already explained, each generator is controlled by its regulator to give a falling voltage characteristic with load, and also compensation is provided for equal load division. In addition a tapping is taken from the swamping resistance in series with the voltage coil of each regulator, a few volts up from the negative bus-bar end. These four tappings are strapped together, and the carbon stack of the master regulator is placed between this common point and negative, that is, in parallel with the sections of the swamping resistances. The pile is actuated by a coil across the positive and negative bus bars, and is arranged to open with falling and close with rising voltage. The combination thus gives substantially constant bus-bar voltage, even though the voltages of the generators individually are tending to fall with load.

Radio and Radar Power Supplies

At about the same time that d-c supplies were being obtained from a "windmill" driven generator, radio power was also derived from a similarly actuated source. This streamlined machine was built to give 0.1 ampere at 1,200 volts and four amperes at ten volts, weighed 20 pounds, and was designed to run at a constant speed of 3,500 rpm. To give this last characteristic a slipping clutch, or a variable pitch "windmill," was used.

Following this, a range of motor generators was built which ran off the aircraft electric system. The outputs were in all cases 80 watts either at 1,200 volts or 600 volts, and the inputs were 12 volts or 24 volts to suit the aircraft main power supplies. These units weighed about 12 pounds and were approximately 4.5 inches in diameter by 11 inches long. An interesting point here is that a limit of 80 watts was placed on radio requirements from the aircraft battery, until the summer of 1939, when the demand suddenly was jumped to 750 watts.

Then came the war, and the urgent need for more and more power for radio and radar arose, and thus was born the engine-driven alternator, which to this day is the method most favored by the British for obtaining this power. The first model to go into production was a single-phase alternator rated 500 watts at 80 volts rms, and when fitted to British engines its speed range was 3,000 to 5,500 rpm. The frequency was 1,300 cycles per second at 3,000 rpm. Incidentally, it is not known by the writer what reasons governed the adoption by the British of 80 volts and the frequency range 1,200 to 2,400 cycles per second as the standards for these supplies.

The design of these alternators permits of a very robust mechanical unit. The field is energized by direct current from the aircraft's main d-c power supply, and no windings are placed on the rotating mass, the field coils being positioned on a conical-shaped projection of the end plate, which is bored to receive a cylindrical part of the rotor. The stator with the a-c windings is fixed to the yoke, and there are 24 teeth on the inside periphery. Aligned with the stator teeth are the rotor teeth, 26 in number, so that a pair of teeth coincide 26 times per revolution. The flux path is thus from the conical projection across the constant air gap to the cylindrical part of the rotor along the rotor to the teeth and across the air gap to the stator teeth. The magnetic circuit then is completed through the yoke. The flux is unidirectional but varies in magnitude because of the variation in reluctance of the magnetic path between rotor and stator teeth and the coincidence of these together with the speed determined the frequency.

Round about this time we were receiving Hudson aircraft built by the Lockheed Aircraft Corporation, and, of course, the aforementioned units were not suitable for the American engines powering those airplanes. A new unit of similar output therefore was produced with the necessary American standard flange and drive shaft. This gave full output at 2,000 rpm and upwards, the frequency at 2,000 rpm being 866 cycles per second.

However, not all aircraft are multi-engined and on single-engined airplanes no pads are available for the alternator if a d-c generator is fitted. To meet this situation, a range of dual machines was produced in which the d-c armature is on an extension of the rotor, and the one body carries the alternator stator and the d-c generator poles. Outputs were 500 watts alternating current plus 500 or 1,000 watts direct current, the variations being on the d-c side, the latter could be a plain shunt machine or one of the self-regulating type.

Recently two more alternators have made their appearance similar in construction to those already described but with increased outputs of 1,200 watts. One is suitable for British engines whereas the other is designed for American drives.

The latest design of dual machine is a combination of this 1,200-watt alternator and the 3,000-watt d-c generator. This unit incorporates all the improvements resulting from experience on previous generators. The d-c portion is a normal six-pole shunt machine with compensating windings, and the alternator half has already been described. Full output is obtained at a minimum speed of 3,000 rpm with air-blast cooling of 100 cubic feet per minute, the frequency at that speed being 1,200 cycles per second. The weight is 51 pounds.

Also under development are engine-driven alternators of 3,500 watts and 6,000 watts capacity, the weight of the former being about 35 pounds while that of the latter is unknown.

In the field of alternating current for aircraft power supplies, the only installation at the moment does not derive the power from an engine-driven alternator through a constant-speed device, but rather from auxiliary generating plants. The system is 110 volts, three phase, 250 cycles, but it is believed that this voltage and frequency have not been definitely frozen for future projects, and it is hoped that standardization with American practice may be achieved. Two units are installed in the aircraft, independent of one another, one being used while the other is a standby. The weight of each is 450 pounds complete. Each alternator is rated 20 kw at 3,750 rpm, and a d-c generator of three kilowatts at 28 volts and an exciter of 750 watts are included in each unit. Some development is going forward with constant-speed devices, an eddy-current coupling being one approach, but the weight of this device is excessive. Another approach is a slipping device with tapered rollers, but no information is available on the progress of this project.

Requirements for Low-Voltage Aircraft Cable

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Synopsis: This paper presents the basic requirements to be expected of any electric cable which is considered for use in aircraft. A few of the problems encountered in forming a cable specification are presented, along with factors to be considered in establishing valid test procedures. The author has not attempted to give solutions to the problems presented, but rather to acquaint the reader with the fact that a major problem does exist in designing an electric cable suitable for use in aircraft, and that many factors which are extremely variable must be considered before an adequate solution can be found.

ELECTRIC wiring designed for aircraft probably is required to withstand a wider range of operating conditions than most other types of electric wiring. This is not surprising since present airplanes, both combat and commercial types, are expected to be able to fly anywhere in the world under all kinds of weather conditions. Repair of a damaged airplane in remote parts of the world must be accomplished with a minimum of replacement parts, and probably only basic tools, such as screw driver, pliers, hammer, and wrench. In many cases repairs can be made only by salvaging parts from other airplanes. If the original electric wiring of an airplane is properly designed, installed, and protected against damage due to overloads, short circuits, insulation failure, abrasion, fluids, and fungus growth, and so forth, a great deal of wire replacement and maintenance will have been eliminated in both combat and commercial types of aircraft, although in combat airplanes the larger percentage of wire replacement is caused by gunfire damage.

The following basic requirements are to be expected of any electric wiring considered for use in aircraft:

1. *Minimum Weight.* Unnecessary weight is expensive in an airplane because it results in a reduction of the performance characteristics and the range. A one-pound increase in the weight of an airplane when empty easily may result in three pounds increase in the gross weight because of the weight of additional structure and fuel needed to carry it. This shows that a considerable reduction of "pay load" results when additional structure and fuel are utilized to carry unnecessary equipment weight.

2. *Minimum Diameter.* Excessive wire diameter reflects itself in extra weight. Bundles of wire with excessive diameter will necessitate larger clips to hold them in place. Routing enlarged bundles through the structure may mean an increase in the size of openings through stressed portions of the airplane and result in weakening the structure unless an additional thickness of metal is used around the openings which have been enlarged. The additional strengthening material means added weight. If the diameter of the bare stranded conductor is larger than necessary, the diameter of the shank of the terminal lugs will have to be increased to accommodate the enlarged wire. An oversize in conductor diameter means that more insulation material and braid will be necessary to cover the wire. The size of the "insulation-grip" type of terminal, sometimes used on smaller-gauge wires, also will be increased. With the realization that most airplanes carry several thousand feet of electric wiring, and some of the larger transport airplanes carry several miles of electric wiring, it is easy to see that a small increase in size in the individual conductor can result in an appreciable increase in the weight of the finished airplane.

3. *Noninflammability.* The insulation on electric cable can be ignited by either a sustained short circuit or a flame external to the wire. If the insulation is not self-extinguishing, the burning wire becomes extremely hazardous, since it may propagate the flame from one point in the airplane to another, and it can ignite other inflammable materials and be the cause of a major fire. This dangerous situation has been intensified in the present-day combat and cargo types of airplane, because of the use of open wiring throughout the airplane. . The insulation on wiring should be self-extinguishing.

4. *Wide Temperature Limits.* Wire and its insulation should show no signs of failure when used in ambient temperatures between +125 and −70 degrees centigrade. A military airplane used in Arctic regions today may be transferred to equatorial regions next week. For maintenance the wire must be capable of being bent and flexed at all temperatures without damage to the primary insulation. For operation the wire must be capable of standing the ovenlike heat in the engine section of an airplane which has just returned from a flight and is allowed to stand in a blazing tropical sunlight while the engine "cools off."

5. *Abrasion Resistance.* The braid covering of an aircraft wire must be capable of withstanding a great deal of abuse in installation and service. During installation and assembly, wiring is subjected to being pulled through small openings and across sharp metal edges, and to general rough shop treatment. In service-vibration and airplane motion may cause the loosely bundled open wiring to beat itself against a piece of structure or chafe against the sides of an opening through which the wire passes.

6. *Fluid Resistance.* Engine oil, hydraulic fluid, high-octane gasoline, salt water, alcohol, ethylene glycol, and any other fluid likely to be encountered should have no effect upon the outer protective coating of the wire. Open wiring in the engine nacelles, wheel wells, and other exposed sections is subject to all of the aforementioned fluids during operation and maintenance and therefore should not be materially damaged by exposure to any or all of them.

7. *Fungus Resistance.* This property is most important for airplanes used in tropical areas where high heat can be accompanied by high humidity. Wiring inside equipment and in confined parts of the fuselage may be attacked by fungus which will cause destruction of wire insulation and require early replacement.

8. *Maximum Current Capacity.* In a 28.5-volt d-c electric system the maximum current-carrying capacity is limited in almost all cases by the maximum allowable line-voltage drop rather than the rating of the wire. The allowable line-voltage drop has been set by specification and is dependent upon the operating requirements of the equipment. In the larger airplanes almost every circuit is carrying only a fraction of the current it is capable of handling because of the voltage-drop limit. A few circuits do carry their rated current, but in these isolated cases the length of wire between the main bus and the apparatus is very short, and the wire capacity can be utilized without exceeding the voltage-drop limit.

9. *High Dielectric Strength.* Within the range of operation of present-day aircraft, pressure altitude and relative humidity changes have no measurable effect upon the dielectric strength of wiring insulation. Pressure altitudes varying from sea level to 50,000 feet, and relative humidity from 0 to 100 per cent are encountered. The test voltage of from 2,000 to 5,000 volts which the finished cable is required to withstand when passing through a chain-electrode spark-test machine is for the purpose of discovering flaws in the insulation material, such as a thin-walled section of insulation, a small chip of metal in the material, an air bubble, or any other flaw which might cause mechanical or electrical insulation failure during installation and service. Low test voltages of a magnitude approximating those maximums that actually may be encountered would not be sufficient for revealing hazardous insulation flaws.

Establishment of a Specification for Aircraft Cable

In order that the wire manufacturers might have a requirement basis upon which the design and construction of an acceptable aircraft cable could be based,

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attempts have been made to formulate a specification for low-voltage aircraft electric cable. To aid in the determination of a specification suitable to the Army and Navy, the aircraft industry, and the wire manufacturers, the Technical Advisory Committee on Aircraft Cable (TACAC) has been established, whose membership includes representatives of these organizations. A specification acceptable to all concerned has been difficult to achieve, since each group has different problems and ideas concerning the same subject. The present specification resulting from extensive investigation is an Army–Navy Aeronautical Specification *AN-J-C*-48.

1. *Performance Specification.* This type of specification presents the performance requirements to be met by a manufacturer's product. Specific test procedures are presented which are considered valid tests for determining whether or not a product is acceptable. Within certain limits, determined by production limitations, design requirements, and specific uses, the manufacturer has considerable freedom in the design and construction of electric cable. Any suitable material may be used, provided the performance requirements are met. This is the most desirable type of specification if the minimum requirements are set high enough, since it encourages the manufacturer to develop new materials and methods of manufacture.

2. *Manufacturing Specification.* This type of specification is the most rigid of all, since it specifies how a product is to be designed, what materials are to be used, and what manufacturing process is to be used. Very little deviation by the manufacturer is tolerated. This type of specification should be avoided unless absolutely necessary, since it does not encourage design development on the part of the manufacturer.

Very few specifications can be classified entirely as one of the preceding types, since most of them are a combination of both types. Wire specifications are mainly of the performance type. In some instances, however, desired wire characteristics can be attained only by use of one known material or manufacturing process, and therefore use of that material or process must be made mandatory. In other instances, several materials capable of yielding the desired characteristics, if properly used, may be known, but it may not be feasible to set up a test procedure which will validly compare the relative merits of the several known materials. In this case, the use of a particular material may be made mandatory until a test procedure is established which will weigh the relative merits of the several materials.

Establishment of Valid Test Procedures

In writing a specification for low-voltage aircraft wire, stating the qualities that a wire should have in order to meet the specification is a relatively easy matter. The most difficult part is the establishment of test procedures which will give a valid measure of whether or not a particular type of wire will have the desired qualities and will be satisfactory for use in aircraft. For every type of qualification test, a large number of variable factors must be considered. Controlled laboratory tests and procedures should be designed to reproduce conditions to which the wires will be subjected during installation and service.

1. To establish a valid test procedure for determination of the flammability of wire the following factors are important:

(*a*). Wiring position is an uncontrolled variable, but is an important variable insofar as fire and flame rate of travel is concerned. Wire insulation will burn more rapidly, and flame will travel more quickly when the wire is held in a vertical position, or at some angle of slope than it will when held in a horizontal position, because the fire will tend to preheat the insulation above the point which is actually burning, and therefore aid in propagating the flame. A large portion of aircraft open wiring is in some position other than horizontal. Because wiring offers a means for carrying flame from one point to another, the flame rate of travel for the worst condition of wire position should be very small. The insulation should be self-extinguishing.

(*b*). Wire size is important in establishing a flammability test. A small wire will burn more readily than will a large wire. The insulation on an *AN*-0 wire will be more difficult to ignite than will the insulation on an *AN*-18 wire, because of the larger mass of copper which will dissipate the heat more rapidly. An *AN*-0 wire may not continue burning, because of heat dissipation by conduction through the copper, but an *AN*-18 wire may sustain or propagate combustion for quite some time.

(*c*). Small wires are loosely bundled together in open wiring systems. If one wire burns, it may ignite others and cause more rapid spread of the fire.

2. In establishing an abrasion test for wire, it becomes difficult to establish limits for the variables, since each organization will have its own requirements regarding the type and amount of abrasion the wire will have to withstand during installation and service. Installation problems and procedures differ so much that an abrasion-resistant wire acceptable to one concern may not be acceptable to another. Different types of abrasion are encountered in installation and service, namely:

(*a*). A cutting type of abrasion, due possibly to a wire resting on the edge of a piece of metal and allowed to move in a direction which would cut the insulation and braid.

(*b*). A scraping type of abrasion, encountered during installation and maintenance when wiring is pulled through the airplane structure.

(*c*). A pounding type of abrasion, caused by airplane vibration which makes the wire beat itself against structure.

All types will be subjected to varying degrees of intensity. The speed of the scraping action, the sharpness of the cutting edge, the weight of the wire or wire bundle, the frequency of impact, among other variables all will vary between wide limits. The difficulty in setting up a procedure to test for all of these variables can be appreciated. The problem is complicated further by the use of different materials in wire manufacture. Comparing abrasion resistances of cotton-braided, glass-braided, and rayon-braided wires is complicated by the use of different impregnating materials and protective coatings. A rayon or glass braid, in general, is inferior to a cotton braid on the conventional scrape-type abrasion-test machine if the same type of protective coating is used. However, by use of the proper impregnating material or coating, a rayon- or glass-braided wire can be made to appear superior to cotton-braided wire on the same abrasion test machine, and yet inferior on another test apparatus which utilizes a different means for abrading the wire. A definite need is indicated for an abrasion test, and suitable apparatus which will compare truthfully the different types of wire on a basis which will account for variables encountered in usage and will give consistent results regardless of material used.

To enumerate the factors affecting all types of specification tests would take considerable more space and time than has been allotted for the coverage of so vast a subject. It is sufficient to say that the problems peculiar to aircraft are many and varied, but are of the utmost importance in assuring a safe, dependable airplane, capable of operation in any part of the world with a minimum of maintenance.

Conclusions

By means of this paper, the author has attempted to show that a major problem of design has been given to the wire manufacturers by asking for an electric cable which will not fail in operation under conditions of:

1. Ambient temperatures from −70 to +125 degrees centigrade.
2. Relative humidities from 0 to 100 per cent.
3. Pressure altitudes from sea level to 50,000 feet.

In addition, the cable is required to be noninflammable, abrasion-resistant, fluid-resistant, and fungus-resistant, and yet still possess minimum weight, minimum diameter, maximum current-carrying capacity, and good dielectric qualities. A similar problem also has been given to the committees and boards which determine the specification test procedures for giving a valid measurement of the previously stated requirements.

The wire manufacturers, the armed services, the working committees, the aircraft manufacturers, and all others concerned with the problem of design, manufacturer, and use of electric cable have done an excellent job in establishing and maintaining the quality of wire that is

Requirements for Aircraft Electric Motors

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DESIGN requirements for electric motors intended for use on aircraft may be classified roughly into performance and construction. These two classifications are not completely independent of one another, as some of the construction requirements will have pronounced effect on the performance characteristics. Performance characteristics may be subdivided into the following headings:

(*a*). Operating voltages.
(*b*). Torque requirements.
(*c*). Rpm limits.
(*d*). Duty cycle.
(*e*). Efficiency.
(*f*). Ambient-temperature conditions.
(*g*). Protection against overheating.
(*h*). Radio-noise output.

Construction requirements may be subdivided into the following headings:

(*a*). Resistance to vibration and accelerations.
(*b*). Corrosion protection, sand and dust resistance.
(*c*). Gearboxes, clutches, and brakes.
(*d*). Types of bearings and lubrication.
(*e*). Limit switches.
(*f*). Provision for emergency hand operation.
(*g*). Method of mounting and bringing out leads.
(*h*). Maximum over-all dimensions.
(*i*). Maximum allowable weight.
(*j*). Maintenance considerations.

The manner in which the preceding requirements are established and the specific reasons for some of the requirements will be outlined briefly in the following paragraphs with particular reference to 24-volt d-c motor applications.

Operating Voltages

Normal operating voltage at the motor is considered to be 27 volts for continuous-duty motors and 26 volts for intermittent-duty motors. In case of failure of the main generators, the voltage under any appreciable load may fall as low as 20 volts, and satisfactory emergency operation of some motors may be specified at this low voltage. Improper setting or malfunctioning of the voltage regulators may permit the line voltage to rise as high as 30 volts occasionally, and the overspeeding thus created must not impair operation nor running balance of the motor. All parts of the motor must be designed to absorb the torque and momentum loads imposed by sudden stoppage of the armature due to jamming of the driven load at the highest service voltage without damage or loosening of parts.

Torque Requirements

For unlimited rotation applications the starting torque required is usually determined by the type of load to which the motor is connected. Motors driving hydraulic pumps and similar accessories are usually required to supply full-load torque at starting. Motors driving fans, blowers, generators, and similar accessories normally require only a fraction of full-load torque for starting. To provide a margin of safety for the higher frictions encountered at low temperatures, shunt- and compound-wound motors should have a minimum starting torque of 175 per cent normal running torque, and series-wound motors should have a minimum starting torque of 300 per cent normal running torque.[1] Normal running torque is defined as the torque corresponding to the horsepower and the rpm appearing on the nameplate.

Many aircraft motors have a load which is not constant, so that continuous torque ratings are meaningless. This is particularly true for linkages employing toggles where the force required increases rapidly at the overcenter position and then decreases. The first step in applications of this type is a thorough study of the load to be operated, by plotting the torque required versus either time or the percentage of operating cycle. Total torque which the motor will be required to deliver at any time consists of the weight loads for ground operation plus maximum air loads due to flight plus any additional loading due to ice accumulations on exposed surfaces, and increased friction due to cold grease, dust, and differential contraction of metallic members.

With the loading curve in Figure 1 the values of maximum torque required and the points at which they occur may be determined. By introducing the maximum time permissible for completion of the cycle and the number of cycles required per hour, the duty cycle and the intermittent horsepower rating required can be established. If a fixed percentage of the cycle need not be completed per unit of time, the varying speed characteristics of a series-wound motor may be used to obtain a reduction in motor weight and to simplify the control required.

Rpm Limits

In the interest of weight reduction, the motor speed must be as high as possible. The upper limit of continuous speed at present is about 12,000 rpm, this limit being imposed by satisfactory ball-bearing operating and life. On larger sizes of d-c motors, the upper limit of speed may be established by the danger of the armature windings and commutator bars being thrown out of position by centrifugal force.

Duty Cycle

Duty cycle is usually specified as so many minutes "on" followed by a certain number of minutes "off." Given the number of complete operating cycles required per hour and using Figure 1 as a basis, the duty cycle of the motor can be established, enabling selection of the lightest motor which will power the application without dangerous overheating. In calculating the duty cycle, allowance must be made for those applications where a large number of short runs, that is, "inching" toward the desired setting, are common, as in wing-flap or trim-tab positioning service. Applications of this kind impose a much more severe duty cycle on the motor than running continuously from start to finish of the operating cycle. Open-type self-ventilated motors save weight for continuous-duty applications, but provide little or no weight savings on highly intermittent-duty applications. In general, an intermittent-duty motor is lighter than a continuous-duty motor of the same rating.

Efficiency

Minimum allowable efficiencies for 24-volt d-c motors from 0.02 horsepower to 4.0 horsepower are specified in Army–Navy specification *AN-M-10*.[1] While these values are intended for military aircraft and may, at first analysis, appear to be unnecessarily low, they represent a sacrifice of efficiency to obtain a lower motor weight. Higher efficiency could be obtained by increasing the amount of copper and iron in the motor being used in present-day aircraft. Their efforts are rewarded by the thousands of airplanes which fly daily with a minimum of failure in the electric systems due to causes other than gunfire. Many important problems, however, are yet to be solved, and their ultimate solution will depend mainly on the continued and coordinated effort of all organizations concerned.

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but usually cannot be justified, because in addition to the weight of the motor, the weight of the extra gasoline required to carry the heavier motor also must be charged against the more efficient design. High efficiency is of much more importance in continously operated motors than in intermittently operated motors.

Ambient Conditions

Operating temperatures for motors mounted in exposed locations on the airplane range from −65 degrees centigrade to +70 degrees centigrade,[1] and this complete range may be encountered within an hour. Location in cabins or other semiprotected locations does not necessarily mean more favorable ambient temperatures, since airplanes are frequently stationed at operating bases where hangers are not available.

Ambient atmospheric pressures vary from 14.7 pounds per square inch at sea level to 2.72 pounds per square inch at 40,000-feet altitude. This reduction in pressure, although slightly offset by the reduction in temperature as the altitude increases, results in decreased weight of air per cubic foot and forced cooling based on a definite number of cubic feet of air per minute will be inadequate unless the necessary allowance is made in calculating cooling air available. Motors located in supercharged compartments ordinarily will not be subject to ambient pressures lower than 9.5 pounds per square inch. Creepage distances satisfactory at sea level must be increased 300 per cent for satisfactory operation at 40,000 feet.

Ambient humidities will vary from 0 to 100 per cent. Service reports from the South Pacific areas disclose that the humid warm climate is particularly conducive to the creation and rapid development of fungus growth on textiles and all other organic materials, including those used for electrical insulation, unless prevented by a fungi retardant included in the insulating varnish or applied over the varnish. Under ideal conditions for growth, enough fungi will develop in one week to fill completely the air gap between armature and pole shoes and prevent the armature from turning.

Motors located in wings or other compartments where explosive mixture of gasoline vapor and air may accumulate must be provided with suitable explosion-proof housings and have excellent electrical bonding between all parts of the motor enclosure and the supporting structure to eliminate any possibility of igniting such mixtures by an electrical discharge between the motor and structure. The resistance between any two metallic components of the motor and between the motor base and the airplane structure must not exceed 0.002 ohm.

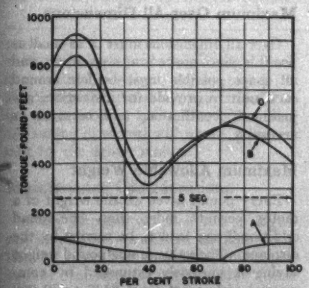

Figure 1. Torque versus per cent stroke for typical aircraft application

A shows torque required for weight of door
B shows torque required to overcome air loads on door
C shows total torque required from the motor

Protection Against Overheating

The question of whether or not thermal protective devices should be required on all motors is very controversial at the present time. For critical circuits, such as propeller feathering, it is obviously unwise to include a "protective" device which will prevent operation of the motor just because it is five degrees above the established safe temperature of the motor windings when unrestricted operation of the feathering pump motor, even though it be severely damaged in the process, would eliminate a dangerous flight condition. On other motors not supplying "time-critical" functions, such as transfer pumps and cabin superchargers, built-in thermal switches protect the motor against unintentional or unsuspected overloads by cutting the motor off the line until it has cooled to a safe temperature. The cycling of the motor due to automatic reclosing of the protective device gives warning to the crew that something is wrong with either the motor or its load, and they may then either clear the trouble in flight or cut the circuit off the line for repair at the next ground stop.

Radio-Noise Output

Greatly increased amount of radio equipment now being used on military airplanes, together with the greater receiver sensitivity and nonshielded wiring installations, have made minimizing of radio-noise voltages imperative. Radio-noise voltages may be generated by d-c motors because of poor commutation, poor combination of stator and rotor slots, and straight slot rotors. The high-frequency voltage ripples may travel either by direct radiation or by conduction along the primary power lines to emerge eventually as an unbearable noise in the radio-receiver headphones. In addition to poor commutation due to improper design, poor seating of the brushes on the commutator has proved a prolific source of radio noise. On a one-eighth-horsepower 1,750-rpm 24-volt-d-c pump motor, for example, the radio-noise voltages measured as shown in Table I.

Table I

Frequency (Kilocycles)	Motor Load	Microvolts on Motor Leads	Radiation Noise at Four-Foot Distance
200	No load	45,000	1.5
200	50 per cent	200,000	1.0
200	Full load	200,000	1.6
600	No load	20,000	12
600	50 per cent	30,000	16
600	Full load	25,000	22
1,000	No load	8,000	1.0
1,000	50 per cent	13,000	1.3
1,000	Full load	21,000	2.0
10,000	No load	70	1.0
10,000	50 per cent	80	1.1
10,000	Full load	100	1.2
20,000	No load	10	1.1
20,000	50 per cent	12	1.2
20,000	Full load	13	1.2

On disassembly the brushes were found to have only 25 per cent area of contact with the commutator. After seating the brushes properly and cleaning the smut from the commutator surface, the radio-noise voltage dropped to 50 microvolts at 200 kilocycles per second and correspondingly less at all the higher frequencies. The radiated-noise field disappeared completely after this treatment.

From a weight standpoint, it is not efficient to apply noise filters to all rotating electric equipment, and, therefore, it becomes necessary to minimize the noise each item of equipment produces and to supply a power-line filter just ahead of the radio receivers.

Resistance to Vibration and Acceleration

Although the terms are often used interchangeably, acceleration and vibration are not the same. Vibration always gives rise to acceleration, but acceleration can exist without vibration. The general formula for acceleration is:

$$\frac{a}{g} = \frac{(2\pi f)^2 r}{386}$$

where:

$\frac{a}{g}$ = number of g's acceleration in feet per second per second
f = frequency in cycles per second
r = peak amplitude in inches (one-half the total excursion)

Values of acceleration and vibration vary widely from one type of airplane to another, and even in different sections of the same airplane. The problem is further aggravated by motor mountings which may be flexible enough to permit resonant vibration, in which case the acceleration may increase as much as 20 times. If resonance is not present,

ability to withstand accelerations of 12g applied at the center of gravity in any direction generally will be satisfactory for aircraft applications, including the acceleration value obtained by landing impact.

Table II indicates the range of vibration and acceleration encountered on a typical twin-engine medium bomber.

Corrosion Protection, Sand and Dust Resistance

Use of light metals, such as aluminum and magnesium, to reduce weight has aggravated the corrosion problem, since steel, copper and other metals lower in the galvanic series in sea water also must be used in the motor, often in intimate contact. Effective and durable protective finishes must be provided between dissimilar metals; otherwise any condensation or salt spray will form an electrolyte, and the aluminum and magnesium will be destroyed rapidly by galvanic action. Severe condensation occurs when a descent is made from the cold air of high altitudes into the warmer air near the ground.

Global operation subjects motors to fine sand and dirt Given sufficient time, this sand eventually will penetrate any seal except the hermetic type. These abrasive particles rapidly grind away bearings, brushes, commutators, switches, and gears once they have gained entrance. The nearest approach to a solution at present is to design as effective a seal as possible and to keep the seal effective by periodic cleaning or replacement.

Gearboxes, Clutches, and Brakes

Gears for aircraft motor applications present a difficult design problem because of the small weight and space allowed for them and the difficulty of providing satisfactory lubrication over the wide range of temperatures encountered. Sintered iron gears impregnated with oil have given satisfactory service on fractional horsepower motors. Hardened steel gears with low-temperature grease have been fairly satisfactory for larger geared motors, but no low-temperature grease yet available is entirely satisfactory at high temperatures. Gears must be capable of absorbing the shock caused by the jamming of the driven mechanism at maximum motor voltage without damage or breakage.

Clutches are specified when the momentum of the armature must be removed from the load to prevent overshooting of the output shaft when the brake is applied, or when the frictional load of the armature and its associated gearing is to be removed from the system to facilitate hand-crank operation.

Bearings and Lubrication

Bearing sizes used on commercial motors are too small to withstand the loads and vibrations encountered in aircraft applications.

In general, ball bearings have proved more satisfactory in service than sleeve bearings, and sealed-type ball bearings are preferred, particularly for the higher speeds. Bearings must be designed to take thrust from both directions. However, because of procurement difficulties, sleeve bearings must be substituted for ball bearings when adequate supplies of the latter are not available. Oil-impregnated bearings have not proved too satisfactory. Excessive lubricant must be avoided. The type of lubricant must be such that it will provide lubrication at the extreme high and low temperatures encountered. The lubricant should not become watery at the high temperatures or go solid at the low temperatures. At present, lubricant in accordance with Army–Navy specification *AN-G-3*[2] is the most suitable for meeting these conditions. Enough lubricant should be provided for 500 hours of operation without attention, with the motor operating in any position.

Limit Switches

To provide the utmost reliability of operation, limit switches should be mounted on the mechanism being operated. In order to simplify wiring, however, limit switches are usually incorporated in the driving motor. Switches used for this purpose must be extremely resistant to vibration and must have adequate current and voltage-breaking capacity both at sea level and at high altitudes. Snap-action contacts are necessary and compactness is important. Means of adjusting the setting of the limit switches from outside the motor must be provided and the setting adjustment locked against changes due to vibration or continued operation of the motor.

Provision for Emergency Hand Operations

Some applications, such as landing-gear actuators, require that means for hand operation be provided in case of failure of the electric system for any reason. The hand-crank extension should not turn when the motor is driving the mechanism, nor should it be necessary to turn the motor armature when operating the mechanism with the hand crank. The torque required to turn the hand crank should be low enough so that one man can turn the crank continuously without requiring the advantage of his full weight. Each application of this kind requires individual consideration to establish the most suitable design.

Method of Mounting and Bringing Out Leads

Type of mounting is determined by the individual application. Flange mountings are lighter than base mountings, but are subject to high stresses due to bending moments, particularly if resonant vibration is encountered. Flange mountings must provide sufficient space to permit insertion and removal of bolts or nuts and adequate wrench clearance for tightening them. Tapped holes directly in aluminum are not satisfactory, and such applications should employ plated-steel inserts.

Leads for small motors not subject to severe vibration should consist of multiple pin receptacle in accordance with Army–Navy specification *AN-W-C-591*.[3] Leads for large motors where suitable *AN* connectors are not available, and for all motors on which severe vibration makes *AN* connectors unsatisfactory, terminal studs should be provided. Terminal studs must be anchored securely against turning. Leads inside motors must be anchored firmly and protected against abrasion.

Maximum Over-All Dimensions

Over-all dimensions must be as small as possible, since space is at a premium, and all space possible must be left around each unit to provide for inspection, adjustment, ventilation, and removal as necessary.

Maximum Allowable Weight

Every pound saved on the weight of a motor permits more than one-pound additional pay load to be carried by the airplane. The value of one-pound weight saving is variously estimated by commercial airlines at from $100 to $1,000 per year. In military airplanes no momentary value can be placed on the ability to carry a few more rounds of ammunition or extra gasoline, but the objective is obviously very important. Motor designs must not penalize reli-

Table II

Location	Total Excursion (Inches)	Frequency (Cycles Per Second)	Acceleration (Ft/Sec/Sec)	Maximum Acceleration at Resonance
Engine accessory case	0.020	50	2.56	
Engine accessory case	0.006	185	10.5	40
Fuselage nose structure	0.007	148	8.0	18
Fuselage cabin structure	0.002	148	2.0	40

Functional Design of Aircraft Electric Actuator Equipment

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IN their order of importance the factors which influence the design of an electric actuator for use on aircraft are:

A. Dependability under extreme operating conditions of:

1. Vibration.
2. Acceleration.
3. Temperature.
4. Altitude.
5. Humidity.

B. Performance of intended function with regard to:

1. Speed of operation.
2. Accuracy of movement.
3. Duty cycle.

C. Safety of operation is provided by:

1. Emergency operation provisions.
2. Avoidance of inadvertent operation.
3. Avoidance of fire hazard.

D. Weight influenced by:

1. General schematic arrangement.
2. Choice of materials.
3. Treatment of materials.
4. Detail design of parts.

E. Availability of component parts influenced by:

1. Importance of application.
2. Production schedule.

F. Cost as a function of:

1. First cost in money influenced by:
(*a*). Simplicity of design.
(*b*). Availability of materials, parts, and facilities.
(*c*). Quantity of units to be produced and production schedule.
2. Cost of maintaining the equipment:
(*a*). Money spent throughout life of the actuator.
(*b*). Flight time lost because of maintenance.
3. Cost in loss of performance due to weight.
4. Cost in loss of pay load due to weight.

The purpose of this paper is not to give detailed instructions, but only to point out to the designer of aircraft electric actuating equipment the points which must be considered in formulating such a design and to indicate the methods of obtaining solutions to the many problems involved. The design of equipment of this nature will be found to be about one-fourth electrical and three-fourth mechanical engineering and should only be attempted by an engineer or group of engineers with broad training and experience in both fields.

Electric actuators on aircraft are used to perform functions such as retracting and extending the landing gear, extending and retracting landing and maneuvering flaps, controlling engine cooling air flow, adjusting control surface trim tabs, handling cargo and bombs, and for many other services. From a study of these applications it is seen that the actuator must be dependable and give satisfactory operation under the conditions encountered in aircraft operation. The actuator will be subjected to vibrations at fundamental and harmonic frequencies to 200 cycles per second at amplitudes that produce accelerations to 20 gravity. Most actuators must be installed without shock insulating mounts and therefore of necessity will be rugged in construction with the electrical control balanced to avoid inadvertent operation of mechanism elements or electrical contacts. The actuator and its control should be suitably designed to operate in ambient temperatures of −65 to +160 degrees Fahrenheit at any altitude to the service ceiling of the aircraft and under all conditions of relative humidity to 100 per cent saturation. This will mean that particular attention must be paid to the selection of lubricants, oil seals, breathing provisions, and corrosion preventing treatments. At altitudes above 25,000 feet the brush life of d-c machines will be materially decreased, and it will be necessary to use especially treated brushes in units that are required to operate for any appreciable percentage of the time at these altitudes. Another point to be considered in high-altitude operations is that the breakdown voltage for a given air gap or creepage is very considerably lower than at sea level.[1] Some investigators have attempted to show that at extreme altitudes the cosmic rays or other radiations have an effect on the electrical performance of contacts and air gaps.

In order to design an electric actuator that will perform satisfactorily it will be necessary to have accurate data concerning the direction and magnitude of the forces required of the unit at all portions of its movement, the speeds required at all points, and the frequency in time at which this movement will be required. With this information and with some knowledge of the actuator mechanism, it will be possible tentatively to select a motor with the proper speed–torque characteristics and to design a suitable electric control system. The accuracy with which the actuator is required to position its mechanical output will be dictated by the type of application and by the mechanical means used to connect the actuator to its load. The most widely used device is the limit switch which is used in conjunction with an electric brake

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ability of operation to save weight, but if considerable weight can be saved by shortening the useful life without affecting the reliability during the shorter life, the saving in weight will justify a higher cost for the lighter motor.

Maintenance Considerations

Every airplane which is not in flight nor immediately available for flight is a liability instead of an asset. Ninety per cent of "the airplane not available" time on the ground is required for maintenance work, with poor weather accounting for the remaining time. Designs which facilitate inspection and maintenance obviously will increase airplane availability.

Of necessity, military maintenance and repairs often are performed at poorly equipped temporary bases by inexperienced personnel outfitted with only the simplest of tools. Consequently, aircraft electric motors must be as simple, rugged, and easy to assemble or disassemble as the designer's ingenuity can make it.

Design features which permit rapid and efficient maintenance of electric motors include the following:

(*a*). Lubrication points clearly marked.
(*b*). Brushes readily removable for inspection and replacement.
(*c*). Spare parts exactly interchangeable without requiring reworking.
(*d*). Army/Navy standard bolts, nuts, and screw threads throughout.
(*e*). Complete identification on a permanent nameplate.
(*f*). Readily removable inspection covers.
(*g*). External adjustments for limit switches, slip clutches, and so forth.

In addition, a complete set of service instructions should be supplied to the aircraft manufacturer, showing sectional views of the motor, detailed disassembly and reassembly procedure, servicing data, spare-parts catalogue, and so forth, so that all these data may be included in the *Erection and Maintenance Manual* supplied with each airplane.

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on the motor. This device gives fairly accurate positioning which may be further improved by adding dynamic braking or plugging provisions to the control system. If extreme accuracy that will not vary with load, voltage, or temperature is required, it will be necessary to build into the mechanical part of the actuator provisions for mechanically limiting the motion and to absorb the kinetic energy of the moving system. In some applications of electric actuators, it may be necessary to stop the motion or cause reversal when the load increases or decreases beyond specified limits. This effect may be conveniently accomplished by measuring the reaction on a stationary ring gear of a planetary system of gearing and thereby obtaining a force that is proportional to the amount of torque being applied to the system. This force may be opposed by springs and the movement thus obtained may be used to operate control-circuit switches.

There are applications of electric actuators on aircraft such as landing gear, wing flaps, engine-cooling control, bomb release, fuel valve, and so forth, where it may be necessary because of safety requirements to provide for emergency operation in case of gun-fire damage or other failure of the mechanical or electrical parts of the actuator system. In the case of landing gear it is common practice to provide either cable control that will release the gear from its actuator and allow it to extend by gravity or to provide for hand cranking of the actuator. In some applications such as wing flaps and engine-cooling-air control it will not be necessary to provide an actual mechanical override on the actuator but it will be sufficient only to install an emergency switch that will by-pass the normal control system and feed power directly to the motors. In the case of electrically controlled bomb racks and fuel valves, it is often required that a direct mechanical override be provided by means of cables.

In nearly all applications of electric actuators it will be necessary to provide against inadvertent operation. Control and power relays should be either of the balanced type or mounted in such a position that a severe acceleration in any direction likely to be encountered will not cause the relay to change the position of its contacts. It will also be necessary to avoid the use of relays that have their natural vibration period within the range of frequencies to be encountered in use. The use of sensitive relays in aircraft control should be avoided if possible, but in cases where they must be used the designer should provide shock-insulating mounts and water- and dust-tight covers.

In cases where the consequences of inadvertent operation of some piece of electric equipment would be very serious, the switches at the control station should be protected with plainly labeled and distinctively colored switch guards. In extreme cases it may be desirable to install two or more control switches in series.

In applications that require, by automatic control, the actuation of several different but related parts of the airplane in a certain definite sequence, it will be necessary for the designer to consider the possibility that the actuator may be stopped or reversed at some point other than the end of a cycle. The control must be designed so that under these conditions the proper sequence of operation is maintained.

There are locations in aircraft where explosive concentrations of gasoline vapor may be present under either normal or damaged conditions and it is very important that this point be considered when designing an actuator system. Motors and control equipment should be located where there is adequate ventilation and where these vapors cannot accumulate, but if this is not possible a weight penalty must be accepted because of the necessary explosion-proof construction.

Weight considerations are of paramount importance in the design of equipment of this nature and must be considered when the electrical and the mechanical schematic diagrams are being made. These schematics should be very complete and at this stage it is advisable to determine all gear ratios, screw leads, speeds of all elements, and all loads. There is an opportunity in a design of this nature to do a great deal of original thinking and the making of the schematic diagrams is the point at which most of the nonroutine work is done.

It should not be attempted in a paper of this length to give detail gear-design procedure but there are several basic considerations that may be covered. In the design of aircraft electric actuators the gearing most likely to be required will be straight spur, internal, bevel, helical, and worm. In work of this class the usual standard gear-design practice is not adequate because of the extreme conditions imposed by weight limitations, space requirements, high speed, extreme ambient temperatures, duty cycles, and life requirements. In these designs it will be necessary to call on experience and testing to a very large extent. Gear blanks may be forged from many of the SAE steels but, because of wartime shortages and restrictions, it may not always be possible to obtain those which are most suitable. In the more highly stressed high-speed applications probably the most satisfactory steel will be a high nickel such as 2515 because of its ductility, toughness, and resistance to fatigue. This is a carburizing type of steel and the gear teeth should be finish ground after heat treatment. Other very satisfactory gear materials will be found to be some of the chrome-molybdenum and the chrome-nickel-molybdenum steels which may be hardened without carburizing. Heat-treated blanks of these materials may be completely machined and then have the wearing surfaces hardened by the high-frequency induction process. As this method of surface hardening will result in almost no distortion it is only necessary that the gears be lapped to obtain extreme accuracy.

In the design of gears for this class of service considerable weight may be saved if forged blanks are used because the controlled grain flow and the small chance of having cracks or inclusions at critical sections will allow much higher stresses to be used.

In the design of these lightweight high-speed gears the designer must call on experience and testing to a very large extent and not follow too closely the accepted practices used in general machinery or automotive design. The best tooth form for the comparatively small highly stressed high-speed gears used in an airplane electric actuator differs from all of the accepted standards in that the pinion has a long addendum tooth which mates with a gear having a correspondingly short addendum.

This is an involute system using a 20-degree pressure angle with a full-depth tooth and has a number of advantages over the American Standard 20 degrees stub-tooth system. By having unequal addendums on the mating gears it is possible to have a pinion with a smaller number of teeth without the necessity of undercutting for mating tooth clearance. As a result the tooth will be thick at the root and will have a greatly increased beam strength. Another advantage of this system of gearing is that being full depth, the arc of action will be greater than that of the 20-degree stub-tooth involute system with the result that smoother action and lower tooth impact loads will be obtained at high speeds. This unequal addendum system of gearing is being considered at present for adoption by the American Gear Manufacturers' Association and has received much favorable comment.

In mounting gears the accuracy of alignment and the rigidity of shafting are of the utmost importance. It is necessary to place very close tolerances on the pitch cylinder tangency of straight spur and of helical gearing and on the pitch-cone tangency of bevel gearing because any inaccuracies in this respect will reduce the effective widths of the gears and reduce the power-transmitting capacity. The problem of obtaining accurate gear position is further complicated by the fact that the bearings on each end of a gear shaft are usually mounted in different pieces of the gear-housing assembly. Another factor that affects the accuracy of tooth engagement is the gear-shaft deflection due to the separating forces set up by the tooth pressure acting at

the 20-degrees pressure angle. It is necessary that this force be calculated for each engagement in the actuator gear train so that the lightest satisfactory shaft may be designed and also so that proper bearings may be selected and provided with suitable supports.

It is not considered practical in this class of work to provide for adjustment for straight spur or helical gearing because of the direction in which these adjustments would necessarily have to be made. When using straight or spiral bevel gearing it is usually advisable to back up the thrust bearings with an adjustment.

The practical limit on the face width for straight spur gearing will be found to be about four times the circular pitch and for bevel gearing about one third the slant height of the pitch cone. The reason for this limitation in face width is the difficulty in obtaining accurate full-width contact at the tooth engagement. However, if it is desirable because of space or other limitations to increase the power-transmitting capacity these face width limitations may be exceeded by using very accurately finished gears and by providing very accurate and rigid mountings.

Planetary systems of gearing are often used in aircraft actuator design because of the high reduction ratios and power-transmitting capacities which may be obtained in a small space and also because the gearing is symmetrical about the center line of the system. In gearing of this type it is common practice to use two or more planet gears in order to get the maximum power transmitting capacity for the minimum weight of gearing and gear case. When multiple planets are used, the gearing and mountings must be very accurate in order to distribute equally the load between these planets. One point that must be borne in mind by the designer of planetary gearing systems is that when two or more planet gears are used the sum of the number of teeth in the ring gear and in the sun gear must be divisible by the number of planet gears in the system. If this rule is not observed the various elements of the system will not mesh properly with each other.

Very good efficiencies may be obtained using either simple or compound systems of planetary gearing, but the high reduction differential planetary is to be avoided if any considerable amount of power is to be transmitted. Because of the high circulating power within the differential system, the over-all efficiency is likely to be too low to be practical. This circulating power may be calculated by analyzing the system to obtain the pressures and velocities at each engagement and will be found to be many times the amount of power being transmitted through the system. As the power lost at each engagement is nearly one per cent of that entering the engagement, the efficiency of the system may easily be determined.

In calculating the strength of gear teeth for use in aircraft electric actuators, the conventional method using the Lewis formula is not found to be suitable for gearing of the quality described here because the weight would be excessive. This empirical formula is very conservative and will result in calculated stresses that are approximately eight times as great as those which are actually obtained in these high-precision gears.

Careful design and testing will show that most of the gears in an actuator of this type may be made with a rather thin web between the hub and rim and that this section may have lightening holes. Another weight-saving measure that is often overlooked is the use of hollow gear shafting.

It will be found in most cases that antifriction types of bearings should be selected for moderate to heavy thrust loads and for pure radial loads above 500 rpm. The higher-speed elements of gearing will most likely have relatively high values of diametral pitch requiring a high degree of mounting accuracy which can only be obtained through the use of ball, roller, or needle bearings. Another point in favor of the antifriction type of bearing is that less trouble due to lowered efficiency will be experienced at extremely low temperatures. The bearings for intermediate stages of straight spur gearing may be of the needle or roller type with the shaft ends held against thrust only by brass disks. When using needle bearings it is necessary that the loads encountered cause only extremely low values of shaft deflection in order to properly apply these loads to the needles and prevent their becoming jammed. When using an aluminum or magnesium gear case with highly loaded ball or roller bearings, it is good practice to press a steel bushing into the recess and use this bushing to support the outer race of the bearing.

It is important in actuators for this class of service to use lubricants that will operate satisfactorily in ambient temperatures from −65 to +160 degrees Fahrenheit. This problem of lubrication is at present receiving a great deal of attention by various research organizations and it is expected that an entirely satisfactory answer will be found in the near future. Seals must be used that will prevent lubricant from being lost from the unit and that will keep dust and water from entering while at the same time permitting breathing with changes in altitude.

In designing an electric actuator for aircraft the availability of all component parts must be considered. If the project is of sufficient importance and time will permit, it will be feasible to develop new materials and processes for use in manufacturing the unit. In alloting time for design, research, and testing, the designer must consider the production schedule that must be followed and the manufacturing facilities that can be made available.

The actual design of the actuator unit will very largely determine the cost of the units in production because of the effect on tooling, procurement of materials, and manufacturing facilities required. If the quantity of units to be produced is large it may be advisable to adopt designs that will involve large expenditures in special dies, molds, and other tooling which would result in a lower over-all cost.

In the total cost of a piece of equipment of this nature the designer should consider the cost in maintaining the unit in airworthy condition throughout its expected life which, of course, will include the loss in revenue incurred by having the airplane out of service for repairs.

As shown by this paper a very great effort must be made by the designer of an aircraft electric actuator to cut the weight to an absolute minimum consistent with the stated requirements. It is also shown that this is accomplished by ingenious design by the proper selection of materials, by the rigid control of processes, and by the insistence of a high standard of workmanship. Every ounce of weight that can be saved shows an increase in aircraft performance in terms of speed, range, and pay load.

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A 40-Kva 400-Cycle Aircraft Alternator

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Synopsis: A-c auxiliary-power systems for aircraft date back to World War I. Recently numerous technical articles have indicated an intense revival of interest in this subject. Heart of any electric system is the generator which supplies electric power to all parts of the system. An alternator, especially designed and built for 208-volt three-phase systems is described in this paper. Light weight and reliability dominate the design, which involved a large number of new and unusual problems.

ALTERNATING current has replaced direct current in large commercial power systems because large amounts of power can be transmitted long distances more economically; alternating voltages can be stepped up or down at will by a transformer; and the polyphase squirrel-cage induction motor, which employs no brushes, is so simple and reliable. These advantages, which also apply in aircraft use, have caused a long-continued interest in a-c systems.[1,6] While this interest is particularly strong now, it is to be remembered that the use of a-c systems in aircraft dates back to World War I when wind-driven alternators with built-in spark gap were used to supply power for radio transmitters. More than ten years ago 600-watt alternators driven by a main engine through a constant-speed drive, were used by the Navy. Prior to the present war two different a-c systems were tried experimentally in different planes: one of these was a single-phase 800-cycle system, the other, a three-phase 120-volt 400-cycle system. Rectified a-c systems with 30-volt d-c outputs of 200–800 amperes have also been proposed.[2]

Vernon Grant and Melville Peters showed in 1939 that the optimum voltage for the electric system of airplanes of 20,000 pounds gross weight or larger exceeds the present universal standard of 28 volts.[10] Because higher system voltages are desirable for large airplanes, alternating current appears preferable to direct current for high-altitude operation. Alternating current is easier to interrupt; moreover, the motors have no brushes and are generally lighter and more reliable. A-c power can supply 85 per cent of the total load and, in addition, it has many advantages as a power supply for aircraft radio.[9]

Weight, of course, is always a primary consideration in aircraft equipment. At a meeting of the AIEE Dayton Section in May 1944 an interesting tabulation of comparative weights of different electric systems was presented. The weight comparison was made for a hypothetical bomber of assumed dimensions, and an assumed gross weight of 150,000 pounds. This comparison is given in Table I.

Viewed in any light, the advantages of alternating current are so great that the development of the alternator described in this paper was initiated.

Alternator Rating and Requirements

Alternators of any desired rating can be built for aircraft service. This paper however, is limited specifically to the description of an alternator having a continuous rating of 40 kva, 208 volts, three-phase, 400 cycles, 75 per cent power factor. Overload ratings for this alternator are as follows:

60 kva at 100 per cent of rated voltage for five minutes.

80 kva at 90 per cent of rated voltage for five seconds.

From a heating standpoint, 150 per cent load for five minutes is a more severe requirement than full load continuously, but overload capacity, of course, is necessary to meet emergency conditions. The 80-kva rating was set up as a requirement for two reasons: to provide capacity for starting a number of motors simultaneously, and to ensure greater stability when carrying a load of 60 kva. These load ratings are based upon 250 cubic feet per minute of cooling air being supplied from a blast tube at not less than six inches water total pressure. An internal fan has been built into this alternator to provide cooling sufficient for a small amount of output—about 25 per cent of rated load—while operating on the ground without the benefit of blast cooling. The alternator is designed to supply a three-phase system with grounded neutral. Six leads are brought out to permit the use of differential protection, which disconnects the alternator from the system in the event of a short circuit, either at its terminals or inside the alternator.

Leads are tagged according to American Standards. *T1*, *T2*, *T3* are line leads, whereas *T4*, *T5*, *T6* are neutral leads. Alternator and exciter connections are shown in Figure 10. The terminal block is stepped to facilitate wiring connections and to avoid interference of leads. Without the stepped arrangement, the leads easily could be short-circuited at the block. A cover is provided for the terminal block to protect the leads and terminals.

Damper or amortisseur windings are incorporated to provide stability when synchronizing and when operating in parallel with other machines.

Careful consideration was given to selection of the operating speed, and 6,000 rpm finally was selected as the highest speed feasible for a machine of 40 kva. But the machine is designed to withstand an overspeed requirement of successful mechanical operation at 9,000 rpm, to correspond with the maximum speed of the drive shaft.

Alternator Size and Mounting Arrangement

All important outline dimensions of this 40-kva alternator are shown in Figure 3. It will be noted that the length is 19 inches and the diameter of the body is nine inches. The 19-inch dimension includes the air connector shown on the right, but does not include the shaft extension and pilot fit on the left. These

Figure 1. Front view of 40-kva alternator showing air connector and mounting band

Figure 2. Rear view of 40-kva aircraft alternator showing bracket and shaft extension

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The authors acknowledge the assistance of J. C. Cunningham, L. A. Kilgore, and E. C. Whitney, of the East Pittsburgh Works, and J. D. Miner of the Lima Works, of Westinghouse Electric and Manufacturing Company.

outline dimensions as a whole conform to specifications of the United States Army Air Forces. The alternator is designed to bolt to the constant-speed drive to make, in effect, a single unit. Pilot fit and splined shaft of the alternator engage corresponding parts of the drive.

Figure 3 also shows an adjustable two-piece mounting ring. This ring with its four projecting ears serves to support the alternator end of the combined unit in the airplane framework. Adjustability of the ring over a range of four inches axially facilitates installation. The body of the alternator, over which the ring is adjustable, is machined to a smooth, accurate, cylindrical contour, so that the ring may be secured firmly in any position within the limits of adjustment.

Coupling to the constant-speed drive is through a replaceable 24-tooth driving spline. Some radial freedom, to allow for a small amount of misalignment between the alternator and constant-speed unit, is provided by use of a stub shaft, the opposite end of which is spline-fitted to the inside of the main shaft of the alternator. A shear section is provided in the stub shaft for protection of the constant-speed drive in case of combat damage or mechanical failure of the alternator. Removal and replacement of the stub shaft does not require dismantling the alternator. If broken, the stub shaft can be driven out easily by inserting a rod in the hollow shaft at the air-connector end of the machine.

Method of Excitation

Excitation is furnished by an integral d-c exciter of conventional aircraft-generator construction, an arrangement chosen after a careful study of all possible methods of excitation. This arrangement is lightest in weight, is less complicated, requires the smallest regulator, and is more stable than any other method considered. On the *XB*-19 airplane, excitation power was obtained from the a-c output, which was rectified and controlled electronically.[3] The latter arrangement inherently means loss of excitation in the event of a fault, and the alternator will not provide enough current to burn clear many types of faults which might occur. This arrangement had the further disadvantages of added weight, and also of appreciable warm-up time for the electronic tubes. Use of an inductor alternator to supply excitation power was considered because of the advantage of eliminating brushes. However, an inductor alternator is heavier than a d-c machine and requires the use of a rectifier, which would need to be mounted in or on the alternator in order to make the latter interchangeable with another unit which might use a d-c exciter. Such an arrangement would be awkward and heavy.

Excitation might have been furnished from batteries or from the d-c power

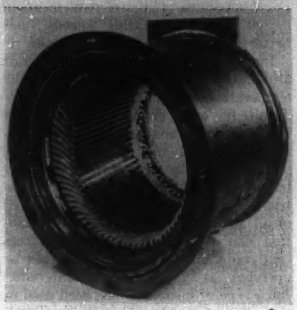


Figure 4. Wound stator before impregnation

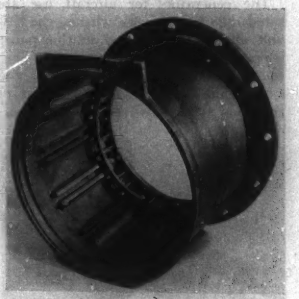


Figure 5. Magnesium-alloy frame of alternator showing internal ribs

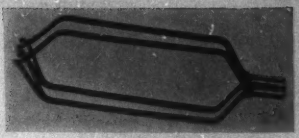


Figure 6. A-c stator coils

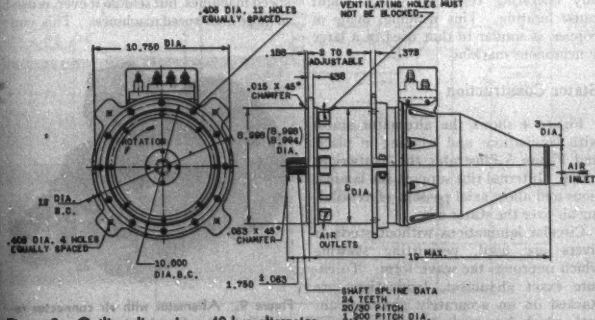


Figure 3. Outline dimensions, 40-kva alternator

Table I. Comparative Weights of Electric Systems

Components	System: 28-Volt D-C Self-Excited Generator	120-Volt D-C Self-Excited Generator	208/120-Volt 400-Cycle 3-Phase Built-In Exciter
1. Generator weight, one unit	150 lb.	120 lb.	80 lb
2. Voltage regulator, one unit	6 lb.	6 lb.	9 lb
3. Main generator breaker, or switch	6 lb.	6 lb.	5 lb
4. Drive shaft from engine	15 lb.	15 lb.	15 lb
5. Constant - speed drive			90 lb
6. Total, items 1 to 5	177 lb.	147 lb.	199 lb
7. Total weight of four units	708 lb.	588 lb.	796 lb
8. Batteries, total weight	55 lb.	55 lb.	55 lb
9. Two 28-volt 6-kw d-c sources of power	0 lb.	125 lb.	100 lb
10. Two 12-kva sources of single-phase 400-cycle power	300 lb.	280 lb.	0 lb
11. Four sets of automatic synchronizing control			40 lb
12. Weight of main power wiring	420 lb.	55 lb.	65 lb
13. Total weight excluding utilization equipment	1483 lb.	1103 lb.	1056 lb

Airplane is a long-range bomber, weighing 150,000 pounds; continuous electric load of 60 kw. Wing spread, 170 feet; length of fuselage, 110 feet; 45 feet to outboard engine; 28 feet to inboard engine. Generator specification:

30 kw continuous, 45 kw for five minutes
Speed range, 3,000–9,000 rpm
Not engine-mounted
Blast-cooled
Altitude, 0 to 50,000 feet

This table was developed at a round-table conference conducted by Major W. A. Barden, United States Army Air Forces, equipment laboratory, Wright Field. Members of conference were: George W. Sherman, Wright Field; L. G. Levoy, R. H. Kaufmann, General Electric Company; J. C. Cunningham, D. B. Fritz, C. G. Veinott, Westinghouse Electric and Manufacturing Company.

Figure 7. Complete pole and field coil of alternator

system of the airplane. Such an arrangement has three principle disadvantages:

1. A fault in the d-c system would cause failure of the a-c system.

2. A larger and heavier voltage regulator would be required, involving a major development, as such a regulator is not now available.

3. There would be an excessive waste of power in the regulator.

Brush life at high altitude—the principal objection to the use of the d-c exciter—was no longer considered the problem that it once might have been, since a successful altitude treatment for brushes is now available.[4] Based on flight experience with d-c generators and altitude-chamber tests on the alternator, the expected brush life at 35,000 feet is approximately 500 hours.

Electrical Design Considerations

Fundamental principles employed in the design of aircraft alternators and d-c generators are the same as those used in the design of standard industrial machines. The elements of an aircraft electric machine resemble those of an industrial machine of far greater physical size. However, in the design of aircraft electric machines, extreme effort is put forth to obtain a given rating at the lowest possible weight; thus, many refinements are required in the electrical and mechanical design which are unwarranted in standard machines.

Electric conductors of aircraft alternators, as well as those of engine-mounted d-c generators, are operated at current densities far in excess of standard machines; 10,000 amperes per square inch is not uncommon[4]—a figure four times as high as used in continuous-rated industrial machines. Magnetic circuits of this 400-cycle aircraft alternator are worked at about the same densities as conventional 60-cycle machines. Because of the much higher frequency, however, the watts loss per pound of magnetic material is from 15 to 20 times as high as in a standard 60-cycle machine. Although the copper and iron are worked harder in aircraft than in industrial machines, the efficiencies of the former are as high or higher for comparable ratings. This is possible because of greater refinements in design, higher operating speeds, and better ventilation of aircraft machines.

Insulation of the windings of aircraft alternators must be suitable for the temperatures encountered. Because indefinite life is not expected and could not be obtained without a great increase in weight, class *A* and class *B* insulating materials usually are operated at higher temperatures in aircraft than for industrial service. Thus, for the life expected of an aircraft alternator, class-*A* insulation can be operated at 130 degrees centigrade and class-*B* insulation can be operated at 150 degrees centigrade.[4] Each type of insulation has been used in this alternator only where its maximum permissible temperature will not be exceeded.

D-c generators for aircraft use are rated at 28.5 to 30 volts, whereas the 208-volt alternator described in this paper is operated at 120 volts to ground. Because of the higher dielectric stresses, the a-c winding is given a potential test to ground of 1,500 volts (rms), and a potential test between phases of 500 volts; alternator field and exciter armature are tested at 500 volts to ground.

Figure 8. Complete rotor showing alternator field, slip rings, exciter armature, and commutator

As in the d-c system, greatest reliability is obtained with parallel operation,[2] and the alternators are designed accordingly. As mentioned before, a damper winding is placed in the pole faces to provide more stable operation of the alternators under any operating condition which might cause hunting. This winding, made of copper, is similar to that used in a large synchronous machine.

Stator Construction

Figure 4 shows the alternator stator with laminations and winding in place, and Figure 5 illustrates the lightweight frame. Internal ribs support the laminations and allow axial passage of ventilating air over the stator core.

Circular laminations without studs or rivets are used, permitting skewing which improves the wave form. To ensure exact alignment, laminations are stacked on an accurately ground mandrel, which has guide bars for aligning the punchings and obtaining the correct skew. While still on the mandrel, the punchings are compressed axially, and a slot is machined in the outer periphery parallel to the axis of the stator. A corresponding slot is machined in one of the ribs of the magnesium-alloy frame, and a rectangular key fits into both slots, thereby locking the punchings.

Stator laminations are held in compression between a shoulder in the frame and a spacer ring held in place by means of six axial through bolts. Openings are provided in the ring and shoulder so that ventilating air can enter the axial ducts between laminations and frame.

A-c stator coils are formed of double-glass-covered rectangular copper wire. Two of these coils are shown in Figure 6. Accurate forming assures that the coils will not touch each other at the ends and that they will have the strength necessary to withstand short-circuit stresses. Class-*B* insulation is utilized in the a-c winding. Paper-and-mica slot cells are used, the paper backing merely providing strength during assembly. Glass sleeving is slipped over the exposed portion of each stator coil. Coils are anchored in slots by means of trapezoidal wedges. After winding, the a-c stator is impregnated with an alkyd resin varnish to resist the moisture, dirt, and fungus growths which an aircraft alternator may encounter.

Rotor Construction

Two obvious methods for constructing the rotating field of alternators such as described in this paper are one-piece laminations and separable poles. With one-piece laminations, the poles and pole faces are integral with the yoke; this type of construction has been used with success in many small machines and in a few large four-pole industrial machines. Since the yoke and poles are continuous, a good magnetic circuit is obtained through the rotating field. However, the one-piece rotor punching has the disadvantage of requiring a random field winding, which is satisfactory in small low-speed machines, but seldom if ever, is used in large high-speed machines. This con-

Figure 9. Alternator with air connector removed, showing front bracket and rocker ring

struction was not adopted in the machine described in this paper because of low mechanical strength and poor space factor inherent in a random winding.

Figure 7 illustrates the separable-pole construction used in this machine. Pole laminations have a rectangular hole in the body, by means of which they are assembled onto a snug-fitting rectangular bar of iron having good magnetic properties. These laminations are clamped together by means of the damper bars, a steel through rivet, and aluminum-alloy pieces which also serve to support the coil ends. Holes are now drilled and tapped through the punchings into the rectangular bar previously described. This construction permits the field coils to be wound directly on the poles.

A heavy layer of fish paper, glass, and mica insulates each coil from the body of the pole. Each coil is wound in two sections of thin copper strap insulated between turns with glass tape. Micarta washers insulate the upper section of the coil from the pole and the coil sections from each other.

After the coils have been wound, they are bolted to a cylindrical yoke and then connected between poles at this time in order to avoid disturbing them later. Wedges are now inserted between adjacent coils in both upper and lower sections. After connecting the coils and inserting wedges, the rotor is thoroughly vacuum-impregnated with an alkyd resin varnish and then baked. Thus, a solid rotor winding is obtained, free of air pockets and impervious to moisture.

Alternator field, exciter armature, commutator, and slip rings form an integral unit. The exciter armature is pressed onto the long shaft, flanged at one end and bolted to the yoke of the alternator field. A shorter flanged shaft is bolted in a similar position to the opposite end of the yoke. Thus, the complete rotor utilizes only two bearings. This construction greatly simplifies assembly of the alternator and prevents any possible internal misalignment.

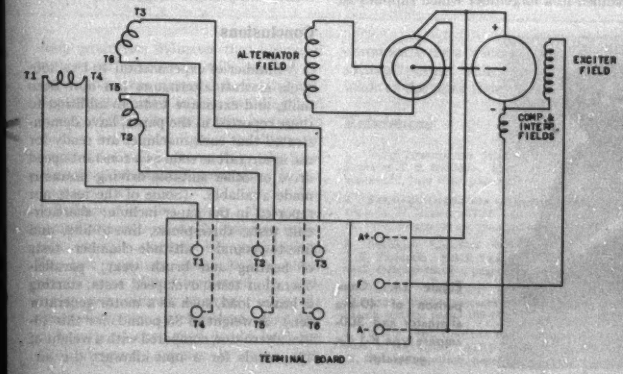
Exciter Construction

The front bracket of the alternator supports the stator of the exciter, as well as the rotor, bearing, and brush assemblies. This construction is illustrated in Figure 9, a view of the alternator with the air connector removed, showing the arrangement of the exciter in the bracket. Exciter brushes and slip-ring brushes are all carried on the rocker ring, which is mounted in the front bracket. By reference to the schematic wiring diagram, Figure 10, it can be seen that the slip-ring brushes are connected directly to the output of the exciter, thus requiring minimum wiring between the exciter and alternator field. To provide maximum excitation for the alternator when required, a compensated exciter with interpoles is used. Two collector rings are mounted at the front end of the rotor, adjacent to the exciter commutator. The rings are shrunk over an insulated steel bushing, which later is pressed onto the exciter shaft.

Figure 11. Terminal board and studs, showing stepped arrangement

Figure 10. Internal wiring diagram and terminal arrangement of 40-kva alternator, including exciter

When rotation is clockwise (at commutator end), phase sequence is T1, T2, T3



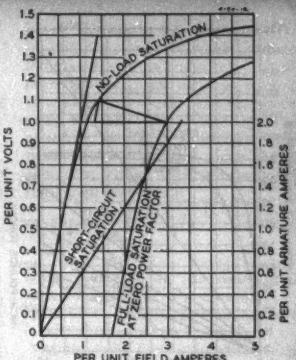


Figure 12. Saturation curves and short-circuit characteristic of 40-kva alternator at 6,000 rpm

Mechanical Design Considerations

Aircraft generators must operate with minimum attention and trouble. No part of a generator is more important to reliable operation than the bearings, and careful consideration must be given to their selection. Sealed or shielded anti-friction bearings offer excellent possibilities for aircraft generators, because they require no attention. Bearings are lubricated at the factory with grease of proper grade and quality to assure long life. When the lubrication is properly applied, a bearing life of several hundred hours may be expected. Because it is in the path of the incoming air, the front bearing is unlikely to become overheated. However, special precautions have been taken to make certain that the rear bearing is adequately cooled. The exciter shaft is hollow, and the front end is open to the incoming air, while at the rear end four holes are provided in the shaft flange. Cooling air passes through the rotor, and then over the rear bearing, thereby preventing excessive temperature rise. This ventilating path serves a second purpose, that of helping to cool the rotor yoke.

To obtain minimum weight, both the front and rear brackets are cast of magnesium alloy. The rear bracket has six arms, channel-shaped for increased strength. The cone-shaped front bracket has four ribs which serve to support the the exciter stator and rocker ring, as well as the front bearing.

Engine-mounted d-c generators are subjected to more severe linear and torsional vibrations than encountered in any other type of service. History of the engine-mounted d-c aircraft generator records a great amount of progress in the solution of the problems involved. Be-

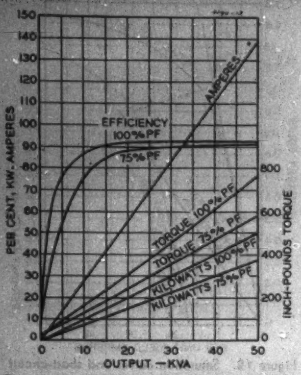


Figure 13. Efficiency, torque, and output curves of 40-kva alternator at 6,000 rpm, from dynamometer tests

cause the alternator of this paper is not engine-mounted, the problem of linear vibrations and accelerations is less severe; however, the machine is subjected to all the vibrations and accelerations occurring in the nacelle structure. Torsional vibration presents a severe problem of undetermined magnitude, because torsional impulses may be transmitted through as well as developed in the constant-speed drive. If the generator is mounted on an auxiliary engine, severe vibrations, both linear and torsional, may be encountered.

Ventilation and Cooling

Ventilation is unquestionably one of the principal factors influencing the weight of any aircraft generator. Without blast-tube cooling,[4] the extremely high outputs per pound of modern aircraft generators would not have been possible. Aircraft-generator builders have been hampered by lack of accurate information on the pressure–volume characteristics of practicable aircraft blast-tube systems. Shall the generator designer use restricted ducts in his machine, or shall he make them as wide open as possible? Few problems are more difficult to solve than the precise answering of this question. In general, the generator designer knows that, with blast-tube cooling, the less air his machine uses, the more total pressure head is available at the generator; and, conversely, that a wide-open generator which uses more air results in less available total head across the generator. Total available head and volume of air could be determined by the generator designer, as pointed out in a recent AIEE paper,[5] from a pressure–volume curve of the blast-tube installation, if the latter were available.

Some general considerations on the qualitative differences in the cooling problem of wide-open and restricted generators will assist in an understanding of the ventilation problem. The significant factor is total temperature rise of the winding hot spot above ambient, which is the sum of two temperature rises:

1. Rise of cooling air passing through the machine.
2. Rise of hot spot above the cooling air.

A wide-open generator passes more air; hence, rise of cooling air is invariably less. But, in the wide-open generator, the dissipating area of the cooling ducts is less, and air velocities in the ducts tend to be lower; the net effect is to cause a higher rise of hot spot above the cooling air. Since total temperature rise is the important factor, it can be seen that the minimum sum of the two factors occurs when the generator is neither too wide open nor too restricted. A complete answer to the ventilation problem requires an analytical or empirical evaluation of the hot-spot rise for different degrees of restriction, taking into account the pressure–volume characteristic of the blast tube.

For the 40-kva alternator discussed in this paper, a total head of at least six inches must be maintained between the inlet and outlet. If the alternator is installed in a large duct which supplies air to the main engine, an exhaust shroud around the outlet ducts of the alternator has to be provided, because the entire alternator is surrounded by air at a relatively high pressure; this shroud must discharge to a region of lower ambient air pressure.

Air ducts have been provided between the outside diameter of the stator punchings and the frame. Air which passes through these ducts also passes directly over the end windings, picking up heat from them as well as from the stator laminations, and from the frame which is a good conductor of heat. Cooling air also flows axially between the field coils of the rotor. The front bearing is cooled by the main blast of air as it enters the alternator, whereas the rear bearing is cooled by air which flows through the hollow shaft, as explained previously.

No effort has been spared to provide the best cooling obtainable with the specified total head of six inches, and the temperature rise has been held down to permissible limits. But it must not be overlooked that, however effective the ventilating system may be, for any given pressure, better results will be obtained from the alternator if higher pressure or more cooling air is made available. By better results are meant lower temperatures of the alternator, with consequent longer life of insulation and bearings, and ability to carry higher overloads of short-time duration.

Performance

Saturation curves of the alternator are given in Figure 12. These curves include: a no-load saturation, a zero-power-factor saturation, and a three-phase short-circuit saturation. Dynamometer tests are recorded in Figure 13, which shows efficiency, torque, kilowatts output, and amperes output, plotted against kilovolt-ampere output. Efficiencies reported here include losses in the exciter, voltage regulator, and alternator itself; they were computed from direct measurements of input and output.

Conclusions

A number of experimental 40-kva 400-cycle aircraft alternators has now been built, and extensive tests, in addition to those reported in the paper, have demonstrated that such machines are ready for use in aircraft as soon as a constant-speed drive or other suitable driving means is made available. (Some of the tests not reported in the paper include: short-circuit tests, three-phase, line-to-line, and line-to-ground; altitude-chamber tests of heating and brush wear; parallel-operation tests; overspeed tests; starting a heavy load, such as a motor generator set.) A weight of 85 pounds for this 40-kva alternator, compared with a weight of 47 pounds for a nine-kilowatt d-c air-

Figure 14. Comparison of 40-kva alternator and 300-ampere type *R*-1 d-c generator

Aircraft Electrical Horizons

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AN ENGINEER needs a goal. In this respect he is no different from the follower of any other profession, art, or trade. Having a goal, every effort and project becomes a step in the final achievement. It is the purpose of this paper to suggest some goals which are on the horizon today. When these goals are reached, it is quite likely that new horizons can be seen. However, let tomorrow take care of itself.

A goal is not only an incentive, it is a pathway. Seeing the need for a device is more than half the act of inventing that device. It can well be that presentation of some of aviation's needs will stir the inventive genius of some engineer who will then create a solution. It is by such steps that we will extend the horizon.

The importance of the electric system looms large today. In former installations the hydraulic and electric systems were not essential to flight. Soon this will no longer be true. Already designers of automatic control apparatus are placing faith in the aircraft electric system. If an inverter delivering a-c power to a turbo supercharger regulator should fail, engine manifold pressure would no longer be controlled; it happens that the engine air-induction system is unstable and a dangerous operating condition can be created in a few seconds. The source of a-c power must not fail. This is typical of situations that emphasize reliability of the electric system.

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Electric-System Protection

Hand in hand with proper reliability of separate electrical components is the necessity for automatic protection of the system from the power sources through feeders and circuits to the individual items of equipment. The state of the latter art is not at all satisfactory; almost without exception protective devices have one or more of the following faults:

1. They do not duplicate the thermal ability of the apparatus being protected.
2. They are too heavy.
3. They have serious errors due to ambient temperature.

For example, circuit breakers are used to protect the cable (not the equipment) of a circuit. A given rating of circuit breaker should permit the cable to carry every ampere that it can safely carry. In fact, if the perfect circuit breaker were developed, it would be designated by an American wire gauge number.

Generators and Motors

The electrical industry can be proud of the progress that has been made in aviation accessories during the last few years. The output from a cubic inch of space and material has been doubled, quadrupled, and doubled again. The engine-driven generator is the best example of this progress. Almost since the beginning of modern aviation the generator designer has been confined to a space of 6 inches diameter and 14 inches length, a volume of 400 cubic inches. Until 1939 this space produced 750 watts, less than 2 watts per cubic inch. Today, nearly 30 watts per cubic inch are developed in that space. The output constant for this type of machine is approaching 20,000, approximately three times the conventional value for the equivalent rating. This constant is derived from the relation

$$c = \frac{D^2LN}{kw}$$

where D and L are dimensions of the active material in the armature, N is speed in revolutions per minute, and kw is output in kilowatts.

At the same time good efficiency has been maintained. At first glance this is surprising since the power loss per pound of material is much higher than in industrial practice. But the number of pounds is reduced until efficiencies are tolerable. This factor is important to aviation; low efficiency means a higher power consumption and this in turn requires the use of fuel at a greater rate. Gasoline weighs six pounds per gallon and an engine requires nearly 0.5 pound per horsepower hour. A generator having an efficiency of 70 per cent will require one pound of fuel per kilowatt-hour.

However, industry has been too prone to modify an existing article to meet a given aviation need. This may be justified in cases of extreme haste or where cost of development must be avoided. But it must be remembered at all times that in aviation a pound saved may be worth its weight in gold.

Similar progress has been made in d-c motors. Just as the specific weight of generators has been reduced to four pounds per kilowatt, so has the weight of motors been reduced to four pounds per horsepower at comparable speeds. Still lower weights are on the horizon and one of the steps to obtain them is higher speed. This will require further development in bearings, lubrication, and commutator design.

craft generator, indicates that electrical outputs of generators still can be expected to increase faster than the weights. Experience gained in the building and testing of this alternator can be used to develop better and lighter machines, or machines of still higher rating; the limit of ratings of aircraft generators is not even in sight!

Perhaps, in the future, direct-connected alternators can be used to maintain aircraft engines in synchronism. For test purposes, these 40-kva alternators were direct-connected to 450-horsepower aircraft engines; after the alternators were synchronized manually, it was found that they would hold the 450-horsepower engines in exact synchronism over a wide range of throttle settings, even while carrying electric loads at the same time.

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Communication Equipment

Much that has been accomplished in the field of radio cannot be unveiled at this time. The importance of these developments can be realized, however, when it is noted that there are as many as 12 complete radio equipments in a large bomber. Each of these is designed for a special task and only a few of them are for radio communication as we know it. These new devices extend the horizons again for each of them presents an interesting peacetime application. And again, the aviation engineer is hoping that the radio engineer has a weight horizon. Much of this new apparatus is unnecessarily large and heavy. This handicap has been overlooked in the necessary haste to obtain useful devices for the war effort. But thoughtful study will eliminate many pounds of equipment weight and much aerodynamic drag from external antennas. Antennas appear to weigh only ounces, but drag increases the horsepower required from the engine and this in turn causes the consumption of many extra pounds of fuel.

Aircraft Lighting

The lighting of aircraft has never been perfect. While much has been done, far more remains undone. The position lights are adequate only in fair weather. A good landing light for fast fighter types is needed. Really satisfactory lighting for the instrument board and the pilot's compartment are yet to be produced. It is unlikely that any passenger is happy with the reading lamps in the modern transport. Failure of a landing-light lamp during testing prior to take-off is cause for a delay since the pilot is compelled to return to the hangar for a lamp replacement. A reserve is needed.

The problem of lighting instruments and the pilot's compartment is the most severe. Many minutes are required for the human eye to accommodate itself to darkness. Yet this dark adaptation can be lost in a second if a bright light is turned on in the cockpit either by design or accident. The lighting of instruments and important controls must be such that they are easily visible without impairing night vision.

Inverter Power Supplies

The development of inverters, direct current to alternating current, has made it possible to utilize alternating current for many small devices, particularly controls and instruments. Both of these uses are worthy of comment.

The inverter has usually been made as a motor generator and the resultant weight and low efficiency are a severe penalty. The penalty is the more noticeable when it is remembered that electric energy is put into the machine and electric energy is taken out. Perhaps, over the horizon is a way of avoiding the change to and from mechanical energy. The vibrator type of inverter has been successfully used at very low power and at frequencies ranging from 60 to 400 cycles per second. At the higher frequency this type will deliver very little power, although this frequency is most suitable for aircraft.

A-c power is well suited to many positioning and control devices since the controlling voltage can be amplified readily. The principle of the self-synchronous motor has been used to advantage in instruments which deliver a remote indication.

Relays and Switching Devices

Other items which receive too little attention are switching devices, and yet all the reliability of the system depends on them. Electric apparatus in aircraft all too often is the cause of an unsatisfactory report, because a relay failed to close, switch contacts welded, moving parts corroded, or any one of several other faults. Practically all of these can be traced to dirt, moisture, or salt air. And all of these can be avoided by hermetically sealing the switch, relay, or magnetic contactor. At the same time this change in design will remove all restrictions on altitude ratings, will make the device explosion proof, may permit an increase in rating, will increase reliability, and it is believed that this can be done at no increase in weight. In fact, weight should decrease if the rating can increase. This type of construction may be a basic requirement for switching devices in the near future.

Load and Equipment Considerations

As many as 150 electric devices have been used in several types of aircraft. This indicates the reason why the electrical load and the installed generator capacity per airplane have increased and are still increasing at a phenomenal rate. As an approximate rule it can be said that the generating capacity in kilowatts should equal the gross weight of the airplane in tons. And in terms of engine power, two per cent of the rated power or three per cent of the cruising power should be reserved for the generator.

In producing these devices the electrical engineer has gone far toward limiting conditions in his use of materials. For example, only the best of magnetic materials are used and these are worked to the limit; the best of materials are fully justified because they save weight. Weight saved is invaluable and the cost of materials is small. An airplane in the transport or bomber class costs $5.00 to $7.00 per pound. Manufacturing costs should be judged by that standard. The aviation engineer hopes that a good magnetic material having the specific gravity of magnesium is just over the horizon.

The current density in conductors has been pushed to new values. Ten thousand amperes per square inch and 125 circular-mils per ampere are often used in continuous-duty apparatus. This requires careful engineering to provide adequate cooling, but the net gain is a considerable reduction in weight. For intermittent-duty applications theoretical current densities of 40,000 amperes per square inch have been used. Better conductors will permit higher densities, or still better cooling will do the same. At one time the use of silver instead of copper was proposed, but this was done not as a matter of conductivity but one of supply.

The current density in carbon brushes is limited only by temperature. Where densities of 40–60 amperes per square inch are conventional, values of 200 amperes per square inch at rated output are common in aircraft generators. With adequate cooling, densities of 600 amperes per square inch are on the horizon.

Power-Distribution Systems

As airplanes increase in size and electrical load, a decision about higher voltages is forced on the aviation industry. The standard for military aircraft is the 24–30-volt d-c system. This standard is likely to include the postwar transport and to supersede the present 12–15-volt d-c system. However, the 24–30-volt system is inadequate when 25–100 kilowatts are being considered and when airplanes with wing spans of 150 feet and more are discussed. A conductor to carry 100 amperes a distance of 100 feet with a voltage loss of 0.9 volt (three per cent of 30) is altogether too heavy.

Since it is a miniature model of a public utility, the electric system of a multiengine airplane presents many similar problems. An increase in system voltage has the same advantages to the aircraft as to the utility company. It is advantageous because it reduces the weight of wiring faster than voltage increases. Theoretically, the wiring weight should be inversely proportional to the square of the operating voltage. This reduction cannot be realized because the insulation becomes a greater proportion of the total conductor weight as size is decreased and because it is not practical to use a wire size of less than number 20 American wire gauge. The latter limitation is due to the structural strength of the conductor.

Two higher-voltage systems are already on this side of the horizon. One is direct current and one is alternating current. The d-c system has much to recommend it; it is similar to the 24–30-volt system already in use. Problems of commutation and switching which were forecast as trouble makers have not been difficult on actual encounter. The progress already made in reducing weight of 24–30-volt equipment applies

equally well to similar items of higher voltage. One of the largest users of electric power is radio, and by a judicious choice of voltages and care in the design of the radio equipment the need for inverters, dynamotors, and power packs can be avoided.

A big advantage of the d-c system is that it is possible to use a battery as a reservoir of energy and as a means of absorbing surges. The ampere-hour capacity of the cells should equal about half the current rating of the generator and there should be as many batteries as there are generators if the battery is to fill its place as a power reservoir properly. The proposed battery would consist of two 48-cell units if the lead-acid type were used. Unfortunately, battery weight for constant watt-hour capacity increases with increasing rated voltage.

The choice of system voltage is a most important problem. At least a portion of the power should be available at the familiar 110–120-volt level to use or adapt apparatus already developed for industrial use. At the same time higher-power loads such as large motors can advantageously use a still higher voltage. This suggests the familiar three-wire system at 230/115 volts. In metal aircraft the neutral wire can be omitted by using a structural ground.

A-C, D-C, and Hydraulic Comparisons

The a-c system has had little practical experience to support claims advanced for it in aviation engineering, although the potential advantages are similar to those which caused its adoption for industrial power. It has several disadvantages to overcome. Paralleling of generators is essential and power usually must be taken from the main engines. Since the latter will seldom operate in synchronism, a speed- and torque-conversion drive is necessary. The drive and generator will undoubtedly weigh more than a d-c generator of equal rating.

Power factor increases the current and therefore the conductor weight. Using a three-phase system, the operating voltage must be at least 40 per cent higher than that of the equivalent d-c system to result in the same weight of conductor. The equivalent of the d-c system described above would be the 208–120-volt four-wire three-phase system and the weight of conductors for equal power would be higher.

Offsetting these disadvantages are the lower weights of a-c apparatus, simpler construction, reduced arcing hazard, improved efficiency, reduced maintenance, flexibility of voltage, and possibly greater reliability and longer life.

Electric apparatus has many advantages over hydraulic and pneumatic equivalents that almost force use of the former for many of the aircraft accessory tasks. Some of these advantages are:

1. Higher efficiency.
2. Lower cost.
3. Ease of installation.
4. Simpler maintenance.

All of these are debatable with a proponent of any other method, but they are the advantages which the electrical engineer must exploit.

On the debit side, the electrical engineer has not delivered enough

1. Reliability.
2. Life.
3. Reduction in weight.

To provide adequate reliability the device must never fail in service and should require no attention for 1,000 hours of airplane operation as a minimum. With simple overhaul, the useful life should be at least five of these 1,000-hour periods. As for weight, a part is always too heavy. In addition, the electrical engineer must fit his device into the needs and requirements of the aviation industry and the operations of both airline and military aircraft.

In 1930 the operating cost for airline transports was approximately 60 cents per ton mile. In 1940 it was 30 cents. Perhaps in 1950 it will be 15 cents. Anything which makes that cost a reality will be welcome. By 1950 it may be possible to operate engines at a fuel consumption rate of 0.37 pound per horsepower-hour instead of the present rate of 0.45–0.46. This economy of operation will require automatic controls, and electric devices are ideal for such applications.

An airplane earns dividends only when it flies. The airlines will want a utilization factor of 60 per cent. This means that the airplane will be in service six hours out of ten. This leaves no time for needless maintenance of awkward electrical accessories.

Other Tasks for Electric Devices

The foregoing remarks have presented attainable goals and requirements. Some other big problems are also on the horizon. For example, one accessory which the electrical industry has never produced is the aircraft wheel brake. For the most part this task is performed hydraulically; it has also been done with pneumatic power. To present the requirements of this problem the assistance of the Goodyear Tire and Rubber Company was sought; R. J. Lammertse and C. E. Ricker, engineers of the wheel and brake division, kindly furnished information on which the following is based. Emphasis has been placed on the particular phases of the problems which are most likely to be difficult to overcome in an electrically actuated brake. The requirements set forth below are divided into two groups, the first dealing with force and torque, and the second dealing with operating characteristics.

1. Force and torque requirements. The brake must produce enough tangential force at the mean friction radius to give a torque of 0.55 WR where W is the weight of the airplane divided by the number of brakes per airplane, and R is the loaded radius of the tire. Usually, the mean friction radius is between 0.3 and 0.5 of the loaded radius of the tire. The normal force required between the friction surfaces will vary inversely with the coefficients of friction of the pairs of material used. For the bimetallic friction pairs used in multiple disk brakes, the coefficient ranges from 0.1 to 0.2, and for molded lining material against chrome plated steel or cast iron as used in drum and single disk brakes, the coefficient ranges from 0.2 to 0.3. These coefficient ranges are determined through experience to be found in the friction material pairs most satisfactory from a wear and durability standpoint. Of course, the force required will also vary inversely with the number of friction surfaces engaging under the same force.

2. One of the major difficulties of an electric control system is to obtain proper load feel comparable to manual operation. This would include all of the following points:

(*a*). Brake torque should be proportional to pedal pressure. This should be true regardless of whether the brake operation is going on or off.

(*b*). Brake operation should go from full- on to full-off position or vice versa with no appreciable time lag.

(*c*). Brake operation must be capable of small changes of torque in either direction without time lag and without returning to brake-off position.

(*d*). The brake must be capable of being held at constant torque during the period of stop.

(*e*). Some means of parking the brake for long periods of time must be provided.

In the design of an electric brake-operating system, it must be remembered that the weight and the space used should be reasonably close to the weight and space requirements of an equivalent hydraulic system. This, of course, applies to the entire system, from the pilot's control down to the brake itself.

Another big problem which is rolling up over the horizon is the prerotation of wheels prior to landing. This is desired to avoid unusual wear of tires upon impact with hard-surfaced runways. It will not require much power, as ample time can be allowed to bring the wheel up to speed. If the electrical engineer can solve the brake problem in less space and weight than is now required for the hydraulic system, there may be space enough for a small electric motor to deliver prerotation of the wheels.

The problems of controlling an airplane, its engines, and some of its accessories increase with aircraft size and again with altitude. For example, it is possible now to build airplanes so large that human effort cannot control them. Power boost is needed. It can be hydraulic or it can be electrical.

At high altitudes pressurized cabins will be a necessity. To operate cables or push rods through the walls of a pressur-

ized cabin requires meticulous care in design, installation, and maintenance. Rotational couplings at the cabin walls are only slightly better. Electric equipment is ideally suited for the solution of this problem.

Automatic controls for flight, engines, engine accessories, heating systems, ventilating systems, and other aircraft luxuries will be a big advantage to the airplane crew. Again electric apparatus is ideally suited for these applications.

Electric Propulsion of Aircraft

The biggest task that is just peeping over the horizon is an electric drive for the airplane. In other words, this means an electric coupling of generator and motor between the power plant and propellers.

Assuming that weight can be kept within reasonable limits, there are a number of advantages favorable to the use of electric-propulsion equipment on multi-engine airplanes.

One of the largest single elements of drag to be overcome in propelling the conventional airplane through the air is due to nacelle and cooling losses, with engines in the leading edges of the wings or in the fuselage nose; this element of drag may amount to from 20 per cent to 40 per cent of the total horsepower requirement of the engines. Because of the relatively small size of an electric motor compared with engines, propellers may be placed where the designer wishes, submerging the motors entirely within the wing or other structural element without recourse to drag-inducing nacelles. In some instances, the weight saving due to the reduced fuel load when nacelles are eliminated may be sufficient to offset the increase in power-plant weight due to the addition of the electric transmission.

With electric drive, the prime movers and generators are located in the fuselage instead of in the wings. In land planes, it may sometimes be necessary to employ a somewhat larger fuselage than normal to accommodate the engines; in the case of sea planes; there is always sufficient space in the hull near or below the water line, a preferred location. With the engines in locations readily accessible to the crew, flight operations may be carried out with standby engines disconnected and all propeller motors running in parallel from a common power bus; and when necessary, simple repairs may be effected on standby units in flight.

Parallel operation of motors will eliminate the entire synchronization problem; and the removal of heavy-overhung engine mounts from wings should permit desirable structural redesign with over-all improvements in structure weights. The concentration of the major mass of the prime mover in the fuselage near the center of gravity of the airplane increases maneuverability and decreases the required control-surface areas; it further provides a convenient recoil-absorbing mass to take the recoil from heavy machine guns and cannon in military aircraft, without the necessity of shooting through a propeller.

Separation of engines from wing structures and the possibility of employing effective shock-absorbing engine mounts may also lead to structural weight savings. Breaking up the motor drives into a large number of lower-power units will also be advantageous in this case, and will permit using small lightweight two- and three-blade propellers with the higher efficiencies inherent in such propellers when over-all design permits, instead of using lower-efficiency three- and four-blade propellers of large power ratings.

A further advantage is the possibility of employing pusher-type propellers instead of tractors, since motors may be sunk in the wings. The increased lift and reduced drag over wing sections in the vicinity of propellers are pronounced at high speeds when propellers are placed behind the wing rather than in front of the wing, thereby reducing turbulence due to the propeller slip stream over the wing.

On the other hand, an electric drive will result in increased power-plant weight, lower efficiency between fuel tank and propeller shaft, increased cost of power plant, and with gasoline-engine prime movers, probably no reduction in maintenance. Further, the installation of engines and alternators in the fuselage of a bomber or cargo airplane may result in disadvantageous bomb or cargo location.

With the above features established, it appears that the most advantageous system would require the use of high-speed high-frequency induction motors and corresponding synchronous generators. Estimates have been made based upon three-phase induction motors to operate in the 400–500-cycle range at a transmission voltage of the order of 1,000 volts, and with turbo-type alternators to furnish power for the motors.

Preliminary analyses have been made and it is believed to be practical to produce an electric coupling, alternator, motor, and controls at the following weights:

Horse-power	Pounds	Pounds Per Horse-power
1,000	750– 850	0.85
2,000	1,200–1,300	0.65
5,000	2,300–2,700	0.54

At each of these ratings the alternator and motor weights will be divided about in the ratio of 60 and 40 if both can operate at approximately the same speed.

The probable advent of high-speed internal-combustion turbines will greatly improve the case for electric drives. The weight and the efficiency loss of the coupling are handicaps and there must be two gains to compensate for them:

1. Compensating reductions in fixed weight must be made in the power plant, propellers, structure, and accessories.

2. The over-all efficiency of the airplane must be improved by eliminating aerodynamic drag to compensate for the lowered efficiency of the coupling.

Storage of Electric Energy

The storage battery is another problem. Perhaps there is no answer, but even with aircraft designs of lead-acid storage batteries, the storage of a kilowatt-hour of energy costs approximately 100 pounds. The same available energy is stored in 0.25 pound of gasoline. Both represent chemical storage of energy.

The electric motor which converts electric energy to mechanical energy weighs less at equal ratings than does the internal-combustion engine which converts gasoline to mechanical energy. The possibilities inherent in the storage of electric energy at 0.25 pound per kilowatt-hour are beyond the horizon and beyond the imagination.

Harnessing of atomic fuel is the most distant goal and it is quite likely that the clue to storage of electric energy at less than 0.25 pound per kilowatt-hour lies at that goal.

The Final Problem

A less tangible horizon is that of public confidence. The performance of structural materials can be predicted, duplicated, and set up in tables. This is not always true of electric apparatus in aircraft. Most people employed in aviation are mechanically minded. They do not understand electricity. To them it is a mysterious phenomenon. They are afraid of it. The news of a failure of an electrical item spreads through the industry, military services, and airline operators at an unbelievable rate. Once spread, all efforts to educate personnel will not eradicate the rumor. Further it is difficult to revise the incorrect operating procedure that may have gone with the failure.

In short, we in the electrical industry must live together. We cannot ignore the troubles of others. The fault of one piece of electric equipment is a discredit to the whole system. D'Artagnan's motto for the three musketeers can well be a slogan for every aviation electrical engineer.

High-Altitude Brush Problem

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THE rapid development of military aircraft during the past three years has been accompanied by an equally vigorous development and use of electric motors and generators necessary for their operation and control. This dynamoelectric equipment covers not only the d-c and a-c applications but also a wide range of power output, voltage, current, and speed. Some of the d-c machines are compensated fully for best commutation, while others are partially compensated, and still others are without compensation and depend on the brush shift and brush grade for satisfactory operation.

The development of carbon and metal-graphite brushes likewise had to keep pace with the development of the electric equipment. At first it seemed that the demand could be met easily, and many standard grades of brushes were used with satisfactory results as long as the planes were flying at low altitudes. However, when the airplanes began to fly at altitudes of 20,000 to 40,000 feet the brushes in many instances were worn out in one to three hours. It became necessary first to determine the causes of the rapid brush wear, and then either to develop treatments for the protection of the existing brush grades, or to make a series of entirely new brush grades capable of withstanding the severe conditions imposed upon them by high-altitude flying, as well as being capable of performing satisfactorily at sea level.

Rapid Brush Wear on Pursuit Planes

In December 1940 a testing program was started in the National Carbon Company laboratory to determine the cause of rapid brush wear encountered in actual flights. The brushes in question are in the motor circuit used for controlling the pitch of the Curtiss variable-pitch propeller. The controlling motor is mounted in the nose or hub of the propeller, which in turn operates the planetary-gear mechanism connected to the blades. The d-c motor is energized through four slip rings which are mounted on the propeller shaft and insulated from it. A stationary brush holder, which is mounted on top of the protective housing, completes the electric circuit to the rings through four rows of small brushes. These are the brushes which were showing rapid wear during flights.

For the first approach of the problem the testing was conducted with equipment made from an actual propeller brush housing and holder (Figure 1). By these means it soon was established that brush temperature and current density had but small effect on brush wear. However, when air with a moisture content of less than 0.15 grain per cubic foot was introduced into the brush housing, rapid brush wear invariably took place after 5 to 30 minutes. Under these conditions the operation of the brushes was accompanied by a loud grinding noise, and a cloud of brush dust could be seen rising from the top of the brush holder. The brushes actually were ground to dust, and in 30 to 60 minutes all of the available brush length was gone.

To meet this problem, two organic lubricants, "*A*" and "12," were developed to be used in conjunction with grade 840-*K* (a copper-graphite material) which was then standard on this equipment. The brushes so treated were designated as *A*-840*K* and 840*K*-12. These two organic treatments provided boundary lubrication on the propeller rings and protected the brushes from rapid wear throughout their life in dry-air atmosphere.

The laboratory findings were checked in actual airplane flights.* For this purpose 15 pursuit ships were used, some of which were equipped with grade 840*K* and the remainder with *A*-840*K* and 840*K*-12. Seventeen sets of 840*K* brushes were worn out, some of them within two hours of flying time; whereas grades *A*-840*K* and 840*K*-12 operated satisfactorily. In one instance grade *A*-840*K* was tested for 112 hours of flying time, and the brushes were not worn out.

This was our first experience with rapid brush wear encountered on military planes. The quick solution provided by the introduction of grades *A*-840*K* and 840*K*-12 was only the beginning of the intensive research which was to follow in the study of the high-altitude performance of carbon and metal-graphite brushes. In the remainder of this paper is given the description of the test equipment used, the results obtained, the theoretical evaluation of the high-altitude problem, and finally its present solution.

* The results of these test flights were given to us through the courtesy of M. E. Cushman, engineering department, Curtiss Wright Corporation, Newark, N. J.

Figure 1. Brush-testing unit for Curtiss variable-pitch propeller

The Atmosphere at High Altitudes

The composition of pure dry air by volume is 78 per cent nitrogen, 21 per cent oxygen, and 1 per cent of ten other gases.[1] These proportions have been found to be essentially the same irrespective of location and for altitudes up to 20 miles. As the altitude is increased there is rapid drop in air pressure, temperature, and moisture content. This is clearly illustrated in Figure 2 in which curve *A* shows the change in air pressure with altitude and curve *B* the change in air temperature and dew point for 100 per cent relative humidity with altitude. The dotted curves C_1 and C_2 indicate respectively the highest and lowest dew-point temperatures for altitudes between 30,000 and 34,000 feet. The data for these two curves were obtained by actual dew-point measurements made in flights at Patterson Field by the United States Air Corps.

In Figure 3 curves *A*, *B*, and *C* show respectively the partial pressure of nitrogen, oxygen, and saturated water vapor with altitude. Curve *D* represents the variation of moisture content of saturated air with altitude. The data for this curve were based on the temperature–altitude curve *B* of Figure 2. At 34,000-feet elevation the air pressure is one fourth of the sea-level pressure, and for this reason the partial pressure of oxygen is reduced by the same factor. The moisture content of saturated air from curve *D* corresponding

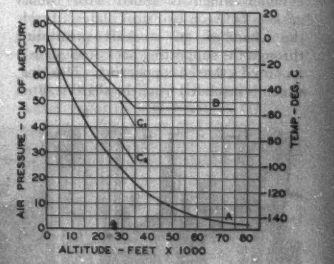

Figure 2

A. Air pressure versus altitude
B. Air temperature versus altitude

Curves *A* and *B* are based on National Advisory Committee for Aeronautics data. Curves C_1 and C_2 are highest and lowest dew-point temperatures measured at Patterson Field

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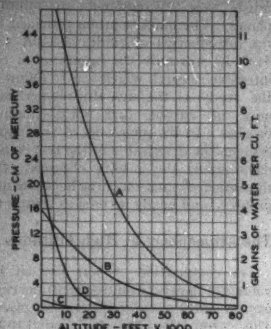

Figure 3

A, *B*, and *C* represent respectively the partial pressures with altitude of nitrogen, oxygen, and saturated aqueous vapor. *D* is the weight in grains of a cubic foot of saturated aqueous vapor versus altitude. All curves are based on National Advisory Committee for Aeronautics data

to 34,000 feet is 0.015 grain per cubic foot. To complete our picture of the atmosphere at high altitudes, that is, 30,000 to 50,000 feet, it may not be out of place to mention that the ultraviolet rays are strong enough to cause the formation of small amounts of ozone and nitrousoxides.

Experimental

Vacuum Chambers

For the study of the operating properties of carbon brushes at reduced pressures and in various atmospheres, two vacuum chambers were used. Both chambers and the auxiliary equipment are shown in Figure 4. Since the two chambers are practically identical in construction it will be sufficient to describe the one on the left which is visible in greater detail.

The vacuum chamber consists of a glass cylinder which is sealed with rubber gaskets between two steel plates. Inside the chamber on a shaft protruding through the supporting back steel plate is mounted a slotted copper ring. This ring, which is insulated from the shaft, is often referred to as a "dummy commutator." There are four radial brush holders symmetrically spaced around the ring. The brush size is two by three-fourths by three-eighths inches. The brush-spring tension is adjustable and can be varied from 0 to 15 pounds per square inch. The ring is 6.125 inches in diameter and is driven by a variable-speed d-c motor.

The outside air is kept from entering the chamber by a special seal on the shaft. A low-voltage d-c source provides the electric current which flows between the brushes and the dummy commutator. The chamber can be closed and pumped to a pressure of 0.5 millimeter of mercury in five to ten minutes. The pressure then can be regulated by a needle valve which controls the flow of dry air into the chamber. The dew point of the dry air used is below −70 degrees centigrade. If desired other gases than air may be allowed to enter the chamber.

The brush temperature is measured by a potentiometer connected to thermocouples inserted in the brushes close to the rubbing surface.

Brush Wear in Various Gases at Atmospheric Pressure

It was already mentioned that carbon or metal-graphite brushes can be made to wear rapidly or dust at atmospheric pressure if the surrounding air does not contain over 0.15 grain of water per cubic foot of air. Such rapid wear in dry air can be stopped either by increasing its moisture content or by increasing its oxygen content over the amount normally contained in the atmosphere.

Brushes wear rapidly also if the surrounding atmosphere is made up of any of the following gases in dry form: nitrogen, hydrogen, carbon dioxide, and argon. Rapid brush wear or dusting does not take place in ordinary room air mixed either with ozone gas or carbon tetrachloride vapor, although the latter does double the brush friction. In general, contaminants present in the atmosphere in the form of fumes and vapors will tend to prevent rather than bring about rapid brush wear.

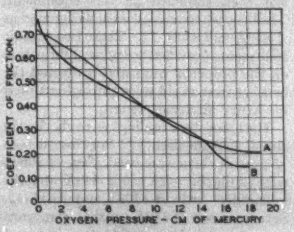

Figure 5

A. Coefficient of friction versus oxygen pressure for graphitized carbon brushes

B. Coefficient of friction versus oxygen pressure for carbon–copper brushes

Brush-spring pressure—11.0 pounds per square inch

Effect of Oxygen, Water Vapor, and Temperature on the Coefficient of Friction and Wear of Brushes

For the experiments with oxygen and water-vapor atmospheres a uniform technique was used. Before each experiment the brushes were heated to a temperature of 300 to 350 degrees centigrade to free them from absorbed moisture. The commutator was heated to 135 degrees centigrade and then quickly resurfaced with a fine-grained commutator stone. The dust was blown away, the brushes were installed, and the chamber was closed. In about ten minutes the chamber was evacuated to a pressure of one millimeter of mercury.

In the experiments with oxygen a steady flow of dry oxygen with a dew point below −40 degrees centigrade was maintained. The rate of flow was limited only by the capacity of the pump at the pressure desired. When water vapor was used the chamber first was evacuated and then water vapor admitted from an evacuated flask. One straight and one inclined mercury gauge were used to

Figure 4. Vacuum chambers used to study the operating characteristics of carbon and metal-graphite brushes at reduced pressures and in various atmospheres

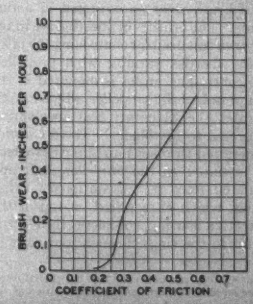

Figure 6. Brush wear versus coefficient of friction for graphitized carbon brushes in dry oxygen atmosphere

Brush-spring pressure—11.0 pounds per square inch

measure the pressure in the chamber.

For the brush-wear measurements a gauge accurate to one-ten-thousandth of an inch was used. Brush-wear measurements were found to be consistent and easy to reproduce. All of the data plotted in Figures 5 to 9 were obtained with a brush-spring pressure of 11 pounds per square inch.

The speed of the dummy commutator purposely was kept low and constant at 1,000 rpm, giving a rubbing speed of 1,600 feet per minute. The driving d-c shunt motor was connected to a constant voltage supply. This made it possible to maintain constant field excitation and use the armature current for measurement of friction.

For the experiments in oxygen and water-vapor atmospheres, two kinds of brushes were used. One was a graphitized carbon grade and the other a carbon grade containing 50 per cent copper. The data for all curves were obtained without the flow of current through the brushes. Brush wear and frictional measurements in an oxygen atmosphere present explosion hazards if electric current is permitted to flow from brushes to commutator.

Tests in Dry Oxygen Atmosphere. The relation between coefficient of friction and oxygen pressure for graphitized carbon and carbon–copper brushes is shown in Figure 5. The differences in coefficient of friction for a given oxygen pressure between curves *A* and *B* are small. The final value of the coefficient of friction for the carbon–copper brushes, curve *B*, is lower than that of the graphitized carbon brushes.

The curves *A* and *B* in Figure 5 would be only of academic value if the relationship between the coefficient of friction and brush wear were not known. This relationship is shown in Figure 6 which is for graphitized carbon brushes. A similar relationship exists for the carbon–copper brushes. The data for this curve were obtained by measuring brush wear and coefficient of friction for different oxygen pressures in the chamber and at as nearly constant brush temperatures as it was possible to obtain. For values of the coefficient of friction between 0.3 and 0.6 brush wear is directly proportional to it. When the coefficient of friction is less than 0.3 brush wear decreases at a faster rate and becomes normal with a coefficient of 0.17. This curve shows further that brush-wear values are large, particularly if one bears in mind that the available brush length for wear in actual practice is one-fourth to three-eighths inch.

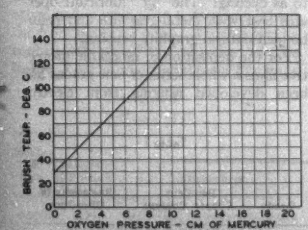

Figure 7. Oxygen pressure at which dusting or rapid wear begins versus brush temperature for graphitized carbon brushes

Brush-spring pressure—11.0 pounds per square inch

Of interest in the experiments with oxygen atmosphere is the relationship between the brush temperature and the oxygen pressure at which rapid brush wear begins.

The curve in Figure 7 shows that at an oxygen pressure greater than 1.1 centimeters of mercury rapid brush wear will not begin with a brush temperature of 40 degrees centigrade. When the brush temperature reaches 130 degrees centigrade an oxygen pressure greater than 9.7 centimeters of mercury is necessary to prevent rapid brush wear. A brush temperature of 130 degrees centigrade corresponds to a commutator temperature of about 100 degrees centigrade. The apparent discrepancy in the amount of oxygen pressure necessary to stop rapid brush wear at the two widely different brush temperatures is undoubtedly due

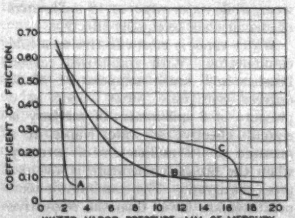

Figure 8. Coefficient of friction versus vapor pressure of water

A. Average brush temperature—60 degrees centigrade

B. Average brush temperature—135 degrees centigrade

C. Average brush temperature—115 degrees centigrade

A and *B* are for graphitized carbon; *C* is for carbon–copper. Brush-spring pressure—11.0 pounds per square inch

to the different amounts of condensed water vapor on the commutator surface. When the brush temperature increases beyond 130 degrees centigrade any condensed water vapor is quickly removed from the commutator surface, and the oxygen pressure necessary to prevent rapid brush wear or dusting approaches a constant value.

The data for this curve were obtained in the following manner: With the brushes and commutator at room temperature, the vacuum chamber was pumped to a pressure of one millimeter of mercury and the commutator brought up to 1,000 rpm. Immediately the brushes began to wear rapidly or dust. Since the brush friction under these conditions was large, the brushes and commutator began to heat up quickly. The commutator temperature was lagging behind the brush temperature about 25 to 30 degrees centigrade.

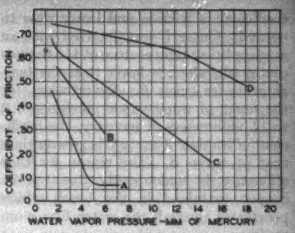

Figure 9. Coefficient of friction versus water-vapor pressure

A. Average brush temperature of 80 degrees centigrade

B. Average brush temperature of 110 degrees centigrade

C. Average brush temperature of 140 degrees centigrade

D. Average brush temperature of 170 degrees centigrade

A, *B*, *C*, and *D* are for carbon–copper brushes

As soon as the brushes began to dust enough oxygen was allowed in the chamber to stop the rapid wear. At this point the oxygen flow was interrupted while the pump was gradually reducing the oxygen pressure in the chamber. When rapid brush wear or dusting began once more the oxygen pressure and brush temperature were recorded. Again enough oxygen was admitted into the chamber to stop the rapid brush wear, and the cycle was repeated. With each succeeding cycle the brush and commutator temperature increased, and thus it was possible to obtain the data of brush temperature and oxygen pressure at which rapid brush wear began.

Test in Water-Vapor Atmosphere. In water vapor the differences in coefficient of friction for carbon and carbon–copper brushes are more pronounced than in oxygen atmosphere. In Figure 8, curves *A* and *B* show the relationship of coefficient of friction versus vapor pressure of water for graphitized carbon brushes. Curve *C* is for carbon–copper brushes.

Curve *A* was obtained with a brush temperature of 60 degrees centigrade. In this case a pressure of water vapor of 2.9 millimeters of mercury is sufficient to lower the coefficient of friction and brush wear to normal. Curve *B* was obtained with a brush temperature of 135 degrees centigrade and requires 19 millimeters of mercury of water vapor to bring the

coefficient of friction and brush wear to normal. Curve *C* was obtained with an average brush temperature of 115 degrees centigrade which is lower than the temperature for curve *B*. Nevertheless, for the range of water-vapor pressures of 2 to 17 millimeters of mercury, the coefficient of friction of curve *C* is greater than that of curve *B*. The reason for that difference is undoubtedly due to the copper contained in the brush which penetrates through the water film more readily.

The effect of brush temperature on the coefficient of friction of carbon–copper brushes in water vapor is perhaps better illustrated in Figure 9. Curves *A*, *B*, *C*, and *D* were obtained with the respective brush temperatures of 80, 110, 140, and 170 degrees centigrade. With a brush temperature of 170 degrees centigrade, 18 millimeters of mercury of water vapor had but little effect on the coefficient of friction and rapid wear of the brushes.

Discussion of Results. The effect of oxygen on the coefficient of friction of nickel sliding on tungsten has been reported by Bowden and Hughes.[2] They found that oxygen at a pressure of 10^{-3} millimeters of mercury was sufficient to lower the coefficient of friction for nickel sliding on tungsten from 6.0 to 1.6. In this instance an attempt was made to obtain photoelectrically clean surfaces.

Experiments with photoelectrically clean carbon sliding on copper will be very difficult to perform. Carbon is heavily loaded with gas. Furthermore, some provision will have to be made to bake completely the chamber, copper commutator, and brushes under good vacuum at a temperature of 500 to 600 degrees centigrade to drive out the adsorbed moisture. The problem, however, is very much simplified by the rapid wear of the brushes. After the brushes have been heated to a temperature of 300 to 350 degrees centigrade and the commutator to a temperature of 150 degrees centigrade or higher, which is sufficient to drive off absorbed moisture, the adsorbed moisture and gases easily can be removed in vacuum as soon as the brushes begin to wear rapidly. Under such conditions films of contamination which might be on the commutator surface are removed in a few seconds. The flow of oxygen which is always maintained in the chamber helps to sweep away contaminants which otherwise may be present.

There is some evidence to show that the oxygen gas protects the sliding surfaces of brushes and commutator from rapid wear, not only by adsorption but also by oxidation.

Water vapor is known to be a good boundary lubricant. On stationary surfaces adsorbed water films are difficult to drive off. On a sliding surface such as a commutator surface, particularly when its temperature is above 100 degrees centigrade, the adsorbed water films can be removed by the brushes in a few seconds.

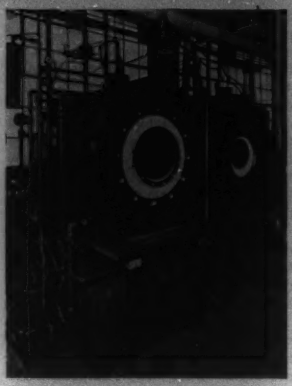

Figure 10. High-altitude chambers used for testing of Amplidynes, motor alternators, inductor alternators, inverters, dynamotors, and other dynamoelectric machines of the motor generator type

Water is ten times as effective as oxygen in reducing the coefficient of friction and preventing rapid brush wear. In general, oxygen pressure of 180 millimeters of mercury is sufficient to prevent rapid brush wear, while water vapor at 18 millimeters of mercury will be equally effective.

Water vapor is most effective on a cold commutator. With graphitized carbon brushes and brush temperature of 60 degrees centigrade water vapor at a pressure of 3 millimeters of mercury is equally effective as water vapor at a pressure of 19 millimeters of mercury when the brush temperature is 135 degrees centigrade. The commutator temperatures are lower than the respective brush temperatures.

As stated before, the data for the curves in Figures 5, 6, 7, 8, and 9 were obtained with two kinds of brushes: one a graphitized carbon grade, and the other a carbon grade containing 50 per cent copper. While the coefficient of friction and rate of wear will be different for brushes of different composition and processing, all brush grades which are not high-altitude type have one thing in common; namely, they wear rapidly, and the coefficient of friction is high under the test conditions previously described.

The Commutator Film

From the description which has been given of the experiments, it is evident that carbon or carbon–copper brushes will operate on a copper commutator with small brush and commutator wear only if there is a film of separation between the rubbing surfaces. This film consists of copper oxide, carbon, adsorbed oxygen, adsorbed water, and contaminants from the air. The contaminants often can be of organic nature such as oil vapors. Once this film is removed the rubbing surfaces of brushes and commutator seize, and quick abrasion of both takes place.

From the fundamental studies of W. B. Hardy[3] we know that when two clean surfaces are brought together within a very close range actual seizure or welding takes place at the points of contact. This seizure is caused by the powerful attractive forces due to the surface atoms. It is further known that these attractive forces are effective only within a very short range, and therefore a boundary film of separation is sufficient to reduce their value to the point where actual welding at the points of contact will not take place. Thus, the whole problem of satisfactory brush operation is reduced to that of boundary lubrication.

At sea level with normal humidity a boundary lubricating film of adsorbed moisture and oxygen is constantly covering the commutator surface. In extremely dry weather, at either sea level or high altitudes, this is no longer possible and rapid brush wear may follow.

The boundary film on the commutator surface can be organic or inorganic. This film will have to be deposited by some means on the commutator surface throughout the life of the brushes. In our solution of the problem it was found best to let the brushes deposit the film. This means that the brushes for high-altitude applications must be processed specially.

In the use of organic films the treatments or processes known as "*A*" and "12" were already mentioned. These two treatments were developed for use on rings. For brushes used on commutators a complex organic lubricant was developed which was designated as "21." This lubricant has low vapor pressure at temperatures as high as 200 degrees centigrade; it is resistant to oxidation; and, what is most important, it provides a film which gives satisfactory brush life, contact drop, and coefficient of friction under high-altitude conditions. This film also does not introduce periodic contact drop fluctuations frequently referred to as cycling. The "21" lubricant operates best with metal-graphite and resin-bonded natural-graphite brushes.

For the deposition of inorganic protective films a whole series of new grades has been developed ranging from electro-

Table I

Grade	Per Cent Copper Content	Resistivity in Ohm-Inch
ANK	75	0.0000091
ALP	65	0.000019
AJT	45	0.00035
AJZ	25	0.00055
AJS	0	0.0023
AMY	0	0.00040
AMZ	0	0.0025

graphitic brushes to metal-graphite brushes containing more than 70 per cent copper. Some of the brush grades developed for high-altitude applications are given in Table I. The operating temperatures which these grades will withstand are limited not by the brushes but by the machines themselves.

Performance of Grade *AJT* in the Vacuum Chamber

Grade *AJT* is a copper-graphite grade containing 45 per cent copper. It was selected as an example because it is typical of all grades with the fine protection it has against rapid wear at reduced pressures. Table II gives brush life and the coefficient of friction in room air at about 50 per cent humidity, room air at 100 per cent humidity, dry air at atmospheric pressure, dry air at 18.2 centimeters of mercury, and vacuum at 0.1 centimeter of mercury.

The amount of copper used in the various grades listed in Table I has a direct effect on the contact drop with which they will operate at a given current density. Excellent brush life, however, has been obtained with all grades under similar test conditions as in Table II.

The High-Altitude Chamber

So far this paper has presented the operation of brushes on copper rings. The final test had to be made on actual electric machines at air pressure, temperature, and dew-point conditions simulating those at high altitudes.

The general appearance of the two high-altitude chambers, which were constructed for tests of dynamoelectric equipment, is shown in Figure 10. The chamber on the left has its front insulating cover removed in order to show the bolted head which closes the chamber. These two chambers which are alike have worked so well from the time of their construction that a brief description may not be out of place for the sake of those who might be interested.

The chamber was constructed from steel pipe 16 inches in diameter and 18 inches long. One end of the pipe is closed by a welded steel plate, and the other end is welded to a flange to which the front cover is bolted. To increase the cooling surface of the chamber on the inside, longitudinal radial steel fins have been welded around the periphery. The chamber is jacketed with a cylindrical steel case forming an annular space for holding a mixture of dry ice and high-boiling-point naphtha. The steel chamber is housed in a wooden box with four inches of heat-insulating material between the steel jacket and the box walls. It is important that the chambers be well constructed to prevent any leakage of room air which would cause frost deposition in the chamber and lead to erratic results.

Table II
Grade *AJT*

Hours Per Inch	Coefficient of Friction	Atmosphere
6,000	0.21	Room air, 50 per cent humidity
38,000	0.25	Room air, 100 per cent humidity
1,200	0.18	Dry air, sea level
1,600	0.19	Dry air, 18.2 centimeters mercury
35,000	0.12	Vacuum, 0.1 centimeter mercury

Under all conditions of operation the chambers are constantly flushed with filtered dry air, the dew point of which is −70 degrees centigrade. This air is never recirculated. The amount of dry air admitted is limited by the capacity of the pump at the pressure at which the chambers are operated. At an air pressure of 19 centimeters of mercury which corresponds to an altitude of 34,000 feet, the air in the chamber is changed 10 to 20 times per hour. At no time is there any frost visible on the inside walls of the chambers. The importance of taking this precaution hardly can be overstressed. This is undoubtedly one of the reasons why test results obtained have always been in close agreement with actual airplane tests made at Patterson Field.

The walls of the chambers are maintained at a temperature of −70 degrees centigrade, although the inside air temperature may rise up to −50 or −40 degrees centigrade, depending on the amount of heat dissipated by the unit under test. The surrounding cold walls help to freeze the impurities which might be given off by the windings of the machines under test. Most of these impurities naturally are swept out by the dry air which flushes the chambers. The low wall temperature also provides a continuous check of the dew point of the air entering the chamber. As long as there is no frost deposited on the chamber walls it is certain that the dew point of the air is lower than −70 degrees centigrade.

Tests in High-Altitude Chambers

The machines tested in the high-altitude chambers cover a wide variety of types and makes. These included Amplidynes, motor alternators, inverters, dynamotors, inductor alternators, and various other types of small machines. The procedure generally used was to operate the machines in room air with the brushes with which they were received and check their input and output ratings. The length of the room air test varied from 24 hours to several days. After this they were tested in the chambers under the high-altitude conditions as described in the preceding section. The load conditions were varied for the different machines. To simulate the actual working load, the Amplidynes were operated under a cyclic load schedule of 10 minutes full load and 50 minutes no load each hour, while the dynamotors carried a full load continuously. On the other hand, it was necessary to operate the inverters and alternators at 50 to 75 per cent of their sea-level rating to prevent excessive heating under the high-altitude conditions. In many instances when the machines were supplied with brushes which had little or no high-altitude protection the brushes wore out in one to five hours. After this the commutators were resurfaced, high-altitude brushes installed, and the tests repeated. Table III gives the life obtained with ordinary and with high-altitude brushes on these machines in the high-altitude chambers.

With some small machines, the output current of which is only a few milliamperes, the commutators and brushes operate at temperatures considerably lower than 100 degrees centigrade. The brushes of such machines even if they do not have high altitude protection may not wear rapidly for several hours or even days because of the effect of condensed moisture on the commutator and quite often because of the condensation of contaminants given off by the windings of the machine.

Effect of Sparking on Brush Life

In the introduction it was mentioned that the machines used today on military airplanes can be divided from the point of view of compensation into three general groups: completely compensated, partially compensated, and without compensation. This has made it necessary to consider carefully the selection of proper brush grades for satisfactory commutation at sea level. Machines without compensation usually use carbon brushes with or without a small amount of copper.

Table III

		High-Altitude Brushes	Ordinary Brushes
	Brush Grade	Brush Life in Hours for 1/16-Inch Wear	Brush Life in Hours for 1/4-Inch Wear
Amplidyne			
Input	*AJT*	250	4
Output	*AJT*	300	4
Dynamotor			
Input	*AJT*	1,100	12
Low-voltage output	*ALP*	960	19
Medium-voltage output	*AJS*	2,100	162
High-voltage output	*AJS*	5,500	119
Inverter			
Input	*AMZ*	1,200	0.9
Inverter			
Input	*AJZ*	214	0.5
Output	*AJT*	346	130
Alternator			
Input	T-171	240	0.3
Rings	*AME*	1,380	440
Inductor Alternator			
Input	*AJZ*	520	6

Instrumentation of 400-Cycle Aircraft Electric Systems

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THE use of 400-cycle alternating current[1] as a power source on large aircraft originates the problem of adequate instrumentation at the distribution panel. Load conditions on a d-c system are determined by the simple parameters of voltage and current, whereas those of the a-c system include frequency and active and reactive power, in addition to voltage and current. Specifically, the flight engineer will require the following information for intelligent operation of the system:

1. Voltage indication, to show whether or not a machine is operating, and as a guide in the adjustment of the voltage regulator.

2. Current indication, to determine whether or not a machine is overloaded. (Overload also can be detected from voltmeter and watt-varmeter indications, but this requires considerable mental effort on the part of the flight engineer.)

3. Active- and reactive-power indication (where two or more generators are operated in parallel), to guide the adjustment of governors for active load division and adjustment of regulators for reactive load division.

4. Frequency indication, to guide the remote adjustment of governors for frequency level where provision for such adjustment has been made.

To summarize, a group of four instruments, namely, ammeter, voltmeter, watt-varmeter, and frequency indicator, together with their associated resistors and current transformer, is desired for use in a-c systems where parallel operation of several alternators is required. Where nonparallel operation is used, either the watt-varmeter or ammeter can be eliminated. For installations using several alternators, duplication of certain instruments such as voltmeters and frequency instruments can be avoided by use of transfer switches. Normally it is expected that it will be necessary to read only one phase voltage, current, and power in each machine. This group of instruments will give the flight engineer reasonably complete knowledge of circuit conditions. In addition to their specific uses, they aid in the location and correction of minor faults and thus prevent major ones. They serve the flight engineer in much the same manner as the flight instruments serve the pilot.

General Requirements—What Size and Weight?

To be specific, we will consider the distribution system of a three-phase 208-wye/120-volt 30-kw 40-kva 400-cycle alternator and determine the minimum size and weight which will characterize a satisfactory group of instruments. All instruments will have a body diameter of $2^1/_4$ inches, standard aircraft flange-mounting facilities, with depths behind the panel to suit the individual elements. All instruments will have scale lengths of approximately 90 angular degrees and a general accuracy rating of two per cent of full-scale value. They must be designed to withstand satisfactorily the vibration, changes in temperature, air density, and humidity which may be encountered in service. Reasonable independence from load conditions, excepting the particular condition under measurement, is also essential. This may be described as the *self-isolating* property of an instrument by which wattmeter indications are unaffected by frequency change, frequency-meter indications are unaffected by vibration or voltage change, and so forth. These, in brief, are the general requirements on which the designs were based.

Measurement of Current and Voltages

Small-panel a-c moving-iron[2] voltmeters and ammeters have been available from American manufacturers for some years. The investigational work thus was limited to the selection of a mechanism of suitable size, as shown in Figure 1, its enclosure in the standard $2^1/_4$-inch case, and determination of its characteristics in relation to the requirements. The instrument constants and conditional errors, as shown in Table I, are believed to be consistent with an accuracy rating of two per cent of the full-scale reading.

Instrument Current Transformer

The continuous current rating of the 40-kva alternators is 111 amperes, and an ammeter-scale capacity of 250 amperes was chosen to provide liberally for overload conditions, which are of prime importance to the flight engineer.

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The authors acknowledge the assistance of L. G. Levoy, Jr., who supplied information on the functional use of the instruments.

The partially or fully compensated machines often use copper-graphite brushes with a copper content of 50 per cent or more.

Electric machines which operate satisfactorily without sparking or with minute sparking at sea level may not necessarily perform the same way under high-altitude conditions. The reason for this is that the contact drop of the brushes decreases with a reduction of air pressure and may not be sufficient to prevent the flow of large circulating currents and intensive sparking. Since high-altitude brushes depend on their satisfactory performance on the boundary film deposited on the commutator, any injury caused to this film by intensive sparking naturally will reflect on brush wear and general brush performance. For this reason any compensation or machine adjustment which designers of electric machines can make to reduce or eliminate sparking will increase the likelihood of successful brush performance under high-altitude conditions.

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Figure 1. Small-panel $2^1/_4$-inch moving-iron ammeter, cover removed

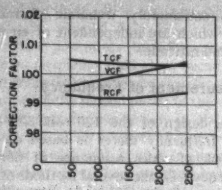

Figure 2. Curves showing correction factors for 400-cycle 125:1 current transformer for line power factor of 0.75, with burden of ammeter, watt-varmeter, and voltage regulator

Ratio correction factor (*RCF*) applies to ammeter reading. Transformer correction factor (*TCF*) applies to wattmeter reading. Varmeter correction factor (*VCF*) applies to var indication when the external resistor furnished with the watt-varmeter is used

To avoid the necessity of running power leads to the instruments and voltage regulator, and to make possible lightweight instrument designs, a special 125:1 current transformer of minimum weight was designed for this application. For simplicity of construction and economy of material, the window type was chosen. This type, with the current magnitudes involved, gave a low number of ampere turns which at 60 cycles would have required a rather heavy core. At 400 cycles, however, the flux required was low enough to permit use of a small core. Further advantage was obtained by using a high-permeability nickel-alloy core material wound in a continuous spiral so as to avoid joints. The secondary coil was wound toroidally on this core, thus practically eliminating any effect of leakage flux.

In order to achieve the minimum weight in this aircraft current transformer, it was designed and compensated for the particular burden with which it was to be used. Furthermore, the ratio and phase-angle errors were made largely to offset each other, thus giving a small

Figure 3. Window-type 400-cycle current transformer for aircraft, 2 1/2-inch diameter

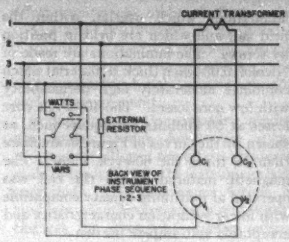

Figure 4. External-connection diagram for watt-varmeter

wattmeter error, even though the phase angle was larger than generally allowed in instrument transformers. These design principles permit the core to be of much smaller cross section than is the case when one transformer must be capable of supplying a range of burdens. Curves of ratio correction factor (*RCF*), transformer correction factor (*TCF*), and var correction factor (*VCF*) are shown in Figure 2. Of course, a transformer designed for a specific burden would be less accurate if used for other burdens, but that does not matter when the burden is definitely known in advance. Similar transformers for other burdens can be made readily by minor modifications of design.

The weight of the 400-cycle transformer, illustrated in Figure 3, is 0.43

Table I. Constants and Performance Data of 2 1/4-Inch 0–2.0-Ampere Ammeters and 0–250-Volt Voltmeters

Average of 16 Samples. Normal Accuracy—Two Per Cent of Full-Scale Value. Weight—0.37 Pound Each

		Ammeter	Voltmeter
Scale Constants			
1.	Length (inches)	1.52	
2.	Angle of deflection (degrees)	85.1	
Moving Element			
1.	Full-scale torque (T) (millimeter grams)	0.24	
2.	Mechanical factor of merit (T/W)	0.52	
3.	Response time (seconds)	1.30	
Volt-Ampere Burden			
1.	Voltmeter at 250 volts (va)	0.27	
2.	Ammeter at 250/2 amperes (va)	0.20	
Performance Data			
	All errors are expressed as a percentage of the full-scale value.		
1.	Full-scale self-heating error	< ±0.3	±0.6
2.	Frequency error		
(*a*).	400–450 cycles	< ±0.3	< ±0.3
(*b*).	400–350 cycles	< ±0.3	+0.5
3.	Ambient-temperature error		
(*a*).	+25 C to +68 C	+0.9	−1.2
(*b*).	+25 C to −38 C	−1.3	+1.8
(*c*).	Permanent change	±0.3	±0.4
4.	Error due to 10 instantaneous applications of 1,000 per cent load to ammeter	±0.6	
5.	Effect of 95 per cent relative humidity at 65 C for 6 hours	±0.3	±0.5
6.	Effect of vibration at 500–3,000 cycles per minute 0.020-inch amplitude	< ±0.3	< ±0.3

Figure 5. Ferromagnetic field structure of watt-varmeter with field-coil winding

pound. This weight advantage results not only from the measures just described but also from the method of support, consisting of a punched aluminum frame over which the winding is placed as shown in the illustration. A transformer of the same type and material for use on 60-cycle circuits would weigh about three or four pounds. The smallest usual 60-cycle current transformer of equivalent current rating weighs about 13 pounds.

Measurement of Active and Reactive Power

Since major loads are balanced and the system neutral is grounded, considerable saving in weight was achieved by the adoption of a single-phase element with the cross-phase connection for the measurement of vars as shown in Figure 4. In selecting the basic element, the following types were considered:

(*a*). Electrodynamic—iron core.
(*b*). Electrodynamic—air core.
(*c*). Induction-disk type.

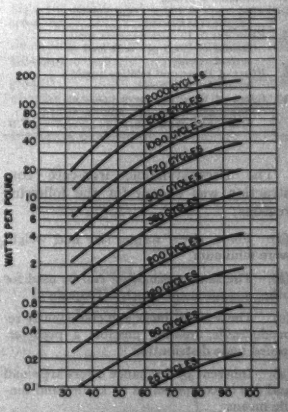

Figure 6. Curves showing typical core loss versus frequency for Nicalol

Table II. Constants and Performance Data of 2¹/₄-Inch Single-Phase Watt-Varmeter Rated 120 Volts, 1.11 Amperes, 133.3 Calibrating Watts With 0–50-Kw Scale for Three-Phase Four-Wire 208/120-Volt System and 125:1 Current-Transformer Ratio

Average of Seven Samples. Normal Accuracy—Two Per Cent of Full-Scale Value. Weight—0.58 Pound Each Including External Varmeter Resistor

Scale Constants	
1. Length (inches)	1.56
2. Angle of deflection (degrees)	90
Moving System	
1. Full-scale torque (T) (millimeter-grams)	0.35
2. Mechanical factor of merit (T/W)	1.06
3. Damping factor	2.0
4. Response time (seconds)	1.1
Potential Circuit	
1. Total terminal resistance (ohms)	12,000
2. Watts loss	1.20
3. Armature resistance (ohms)	46
4. Armature reactance 400 cycles (ohms)	3.2
5. Maximum temperature rise of resistor spools (degrees centigrade)	37.5
Current Circuit (Field)	
1. Resistance (ohms)	0.10
2. Watts loss	0.12
3. Volt-ampere burden at rated current	2.5
4. Temperature rise (degrees centigrade)	18

Performance	Per Cent Full-Scale Value
1. Self-heating error (120 volts, 1.11 amperes, 400 cycles)	−0.5
2. Frequency error, unity power factor	
(a). 400–450 cycles	<−0.3
(b). 400–350 cycles	<−0.3
3. Ambient-temperature error	
(a). +25 C to +68 C	+1.1
(b). +25 C to −38 C	−2.1
(c). Permanent change	−0.5
4. Low-power-factor error at rated volt-amperes	
(a). 0.8 power factor	−0.5
(b). 0.5 power factor	−0.7
5. Varmeter operation	
(a). Zero power factor at instrument, rated volt-amperes	±0.9
6. Voltage error	
(a). 120–132 volts	+0.3
(b). 120–108 volts	−0.3
7. Sustained overload	
(a). Six hours at 100 per cent voltage, 120 per cent current	±0.3
8. Error due to 10 instantaneous applications of 1,000 per cent load to current circuit	<±0.3
9. Effect of 95 per cent relative humidity at 65 C for 6 hours	+0.5
10. Effect of vibration for 2 hours at 500–3,000 cycles per minute at 0.020-inch amplitude	±1.0

The electrodynamic iron-core construction was chosen for the following reasons:

(*a*). For a given torque size and weight were minimum.

(*b*). The same mechanism can be used for other measurements, such as frequency.

(*c*). The scale is linear and consistently reproduceable, making possible a predetermined scale distribution.

(*d*). Inherent performance errors are small and can be compensated by known and simple means.

The magnetic structure of the watt-meter, Figure 5, comprises two stacks of laminations which overlap within the field coil and which are held in position by screws. The laminations are made of Nicaloi, 0.004 inch thick, a material which combines moderately high permeability with low core losses. The 400-cycle core losses at 50 kilolines per square inch, as shown by the curves of Figure 6, are more than 18 times the 60-cycle value. The magnetic material within the coil was operated at maximum density compatible with linear saturation characteristics and acceptable volt-ampere burden.

The electric circuit of the wattmeter, Figure 7, is composed of the field or current circuit and the armature or potential circuit. Each circuit is insulated from the other and from ground. The armature circuit includes two adjustable resistors and a reactance unit. These internal resistors provide an adjustment range of ±8 per cent of the instrument reading and are used for calibration adjustment during manufacture. The reactance compensates for the low-power-factor error originating from the phase-angle difference between field flux and field current due to core loss in the magnetic material. It introduces a corresponding phase-angle lag between potential-circuit voltage and armature current. The compensation is very good in the operating frequency range, and the maximum recorded instrument error at any load, zero power factor, did not exceed 1.5 per cent of the full-scale reading. The low-power-factor error is of importance when the instrument is used as a varmeter.

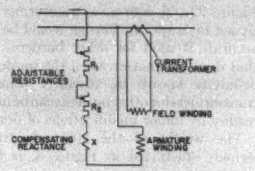

Figure 7. Electric circuit of 400-cycle watt-varmeter

Series reactance is used in the potential circuit to compensate for the phase angle between field flux and field current when measuring vars

Since the reactance of coils at 400 cycles is 6.7 times as great as at 60 cycles, it was necessary to use minimum ampere turns on the field to minimize the volt-ampere burden on the transformer. For this reason, the potential-circuit resistance was designed for 100 ohms per volt. At power frequencies, this resistance could be increased to 1,000 ohms per volt.

The constants and performance of the watt-varmeter, Table II, show reasonable conformity with the objectives of the design. The magnetic damping system, illustrated in Figure 8, consists of a small U-shaped Alnico II magnet and 0.008-inch aluminum disk. This system produces satisfactory dynamic characteristics which are independent of air density and altitude.

Measurement of Frequency

The design of the 120-volt 350–450-cycle frequency meter is based on the principle of series resonance at normal frequency. Of the several methods of application of this principle, the circuit which appeared to yield the minimum weight and size is that illustrated in Figure 9. This circuit consists of the field coil, further shown in Figure 10, and a moving coil connected through capacitor, reactor, and resistor to a secondary winding on the field coil.

The operation of the instrument is explained best by reference to the vector diagram. The field current, I_f, produces a field flux, ϕ_T, which induces the armature-circuit voltage, E_a. The flux ϕ in the air gap at the armature is a portion of ϕ_T. The reaction between ϕ and the armature current, I_a, produces the deflecting torque. At resonance, approximately 400 cycles, the armature current, I_a, is in quadrature with the field flux, and no torque is produced. At 350 cycles the armature current, I_a, leads the armature voltage, E_a, and produces a down-scale deflecting torque proportional to $I_a \sin \alpha$. At 450 cycles the armature current lags the voltage and produces an up-scale deflecting torque also proportional to $I_a \sin \alpha$. These deflecting torques vary with frequency, and true frequency indication is obtained by the addition of a restoring torque which is a function of the line voltage and armature displacement from the center scale position. This restoring torque is produced by a small *Mu*-metal vane[3] fixed to the

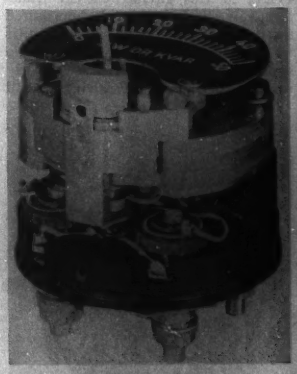

Figure 8. Small-panel 2¹/₄-inch electrodynamic 400-cycle watt-varmeter with cover removed

The internal adjustable resistors are mounted on the insulating base

armature shaft which tends to align itself with the parallel field flux. This construction minimizes the influence of voltage on frequency indication because both the deflecting torque and restoring torque vary with the second power of the voltage.

The transformer shown in the circuit diagram, which consists of two windings on the same spool, is used to energize the armature circuit because the phase angle between E_a and ϕ will not change with increase in field resistance due to self-heating. Since no deflecting torque is produced at resonant frequency, changes in armature resistance do not appreciably affect accuracy at mid-scale frequencies.

The scale distribution, as analyzed in Appendix I, is open and readable throughout the frequency range, although not quite symmetrical with respect to the 400-cycle reference point.

Connections to the armature winding are made through low-torque spirals which are positioned to pull the pointer off scale to the left when the instrument is de-energized. This extraneous torque introduces a small voltage error and slightly changes the resonant-frequency adjustment.

In calibrating the frequency meter three adjustments are required:

1. The restoring torque is determined by the factory setting of the angular position of the armature vane.

2. The deflecting torque is adjusted to give the proper scale length by variation of the series rheostat, the effect of which is shown in Figure 11.

3. The pointer position is set by adjustment of the reactance.

To facilitate calibration, both coarse and fine adjustments are provided. The parallel lines, Figure 12, show that the pointer position can be controlled by this change in reactance without altering the scale length. These adjustments are used in the initial setting of the calibration at the factory.

Magnetic shielding of the frequency meter was necessary to eliminate stray fields which otherwise would produce a phase-angle change between the field flux in the transformer and that acting on the armature.

The characteristics and performance are tabulated in Table III. The minimum torque of the frequency meters is 33 per cent more than that of the wattmeters because of the heavier armature. The ratio of torque to armature weight varies from 0.5 to 1.0, depending on scale position. Ambient-temperature errors are due principally to changes in resistance of the armature circuits, the ohmic resistance of which is approximately 25 per cent copper. Changes in core loss with temperature introduce phase-angle errors. Both sources of error originate from the space limitations of the device. The performance is best in the operating range around 400 cycles.

Table III. Constants and Performance Data of $2^1/_4$-Inch 120-Volt 350–450-Cycle Self-Contained Frequency Meters

Average of Four Samples. Weight—0.83 Pound Each. Conditional Errors Are Expressed in Cycles

Scale Constants			
1. Length (inches)			1.53
2. Angle of deflection (degrees)			87.5
Moving System			
1. Equivalent* full-scale torque (T) (millimeter grams)			0.43
2. Equivalent mechanical factor of merit (T/W)			0.53
3. Response time† (seconds)			1.80
Volt-Ampere Burden at 120 Volts 400 Cycles			
1. Current (amperes)			0.113
2. Volt-amperes			13.6
3. Watts			1.9
Performance	**350 Cycles**	**400 Cycles**	**450 Cycles**
1. Self-heating error at 120 volts	+3.8	+2.8	+1.4
2. Voltage error			
(a). 120–132 volts	+3.3	+0.5	−4.6
(b). 120–108 volts	−3.5	−0.8	+3.6
3. Ambient-temperature error			
(a). +25 C to +68 C	±1.3	±0.9	±1.8
(b). +25 C to −38 C	−5.0	−3.9	−0.7
(c). Permanent change	±0.9	±1.0	±0.9
4. Effect of 95 per cent relative humidity and 65 C for 6 hours	< ±0.3	< ±0.3	±1.1
5. Effect of vibration for 2 hours at 500–3,000 cycles at 0.020-inch amplitude	+0.4	< ±0.3	+0.8

* This is the product of the torque gradient at 400 cycles and the scale angle.

† The interval required for the pointer to indicate true frequency when instrument is energized at 400 cycles 120 volts.

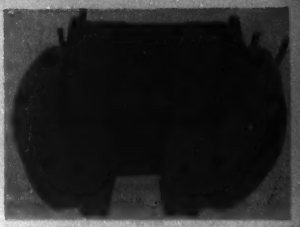

Figure 10. Ferromagnetic field structure of frequency meter with field-coil winding and internal transformer

Conclusion

The weight summary of Table IV compares the instrumentation of the 400-cycle a-c system with that of a 27-volt d-c system of equivalent capacity. The major component of the d-c system is the 1,200-ampere 50-millivolt shunt, while the weight of the a-c instrument group is more uniformly distributed with no single value exceeding one pound. The totals are substantially equal, and thus it is shown that the a-c instrumentation, including the measurement of watts, vars, and frequency, by careful design, can be accomplished without weight penalty. The function of instrumentation is the presentation of information in a manner suitable for quick and adequate perception. This factor has been fully recognized by designing instruments of uniform size, method of indication, and scale length, as shown in Figure 13. Uniform dynamic characteristics are obtained by magnetic damping of the moving systems. Performance data, while preliminary in char-

Table IV. Weights of Typical Sample $2^1/_4$-Inch Aircraft-Power Panel Instruments

Instrument	Weight in Pounds D-C System	Weight in Pounds 400-Cycle A-C System
Ammeter (instrument only)	0.40	0.37
Voltmeter	0.41	0.37
Watt-varmeter		0.58
Frequency meter		0.83
Transformer		0.43
Shunt	1.80	
Total	2.61	2.58

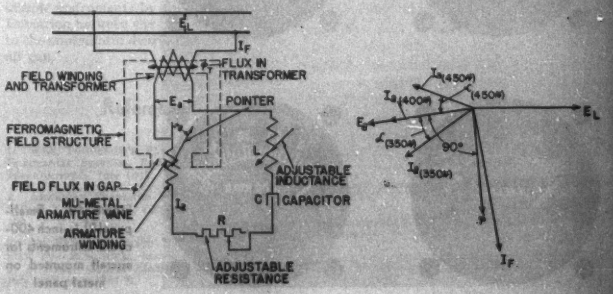

Figure 9. Electric circuit and approximate vector diagram of 400-cycle self-contained $2^1/_4$-inch frequency meter

Operation depends on the unique variation with frequency of the phase angle between the armature current, I_a and the field flux, ϕ

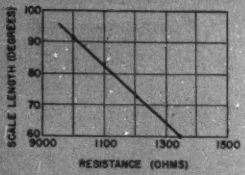

Figure 11. Curve showing scale arc length versus armature-circuit resistance for frequency meter

acter and including neither field nor flight tests, show no serious limitations in either accuracy or durability.

Appendix Calculation of the Scale Distribution of the Frequency Meter

The scale distribution of the frequency meter may be predetermined mathematically from the circuit constants and physical arrangement of the instrument parts shown in Figure 9. The three torques acting on the armature are evaluated and the equation of the scale distribution derived by equating their sum to zero. Numerical solution is obtained by applying the boundary conditions defined by the scale length and frequency range. Comparison of calculated with actual values is shown by the curves of Figure 14.

Assumptions

To simplify the solution the following assumptions are made:

1. The flux, ϕ, in the air gap is uniform, parallel, and normal to the pole faces.

2. The flux, ϕ, in the air gap is in phase with the flux, ϕ_T, in the field-coil transformer.

3. The flux, ϕ, in the air gap leads the armature voltage, E_a, by 90 electrical degrees.

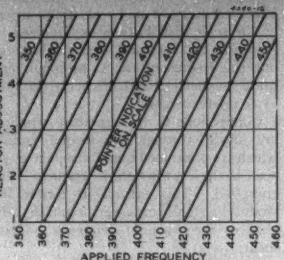

Figure 12. Curves showing range of adjustment for calibrating the frequency meter by changing armature-circuit inductance by means of the adjustable reactor

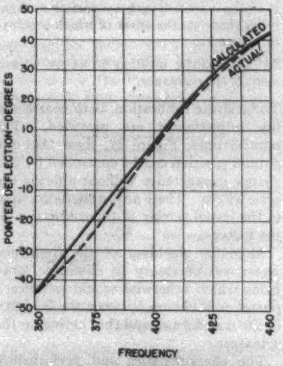

Figure 14. Curves showing actual scale distribution of one sample frequency meter and the theoretical distribution calculated from the known circuit constants and physical arrangement of the instrument parts

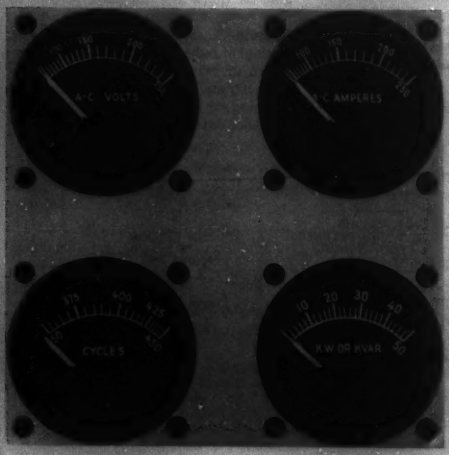

Figure 13. Small-panel 2½-inch 400-cycle instruments for aircraft mounted on metal panel

4. The moving system is perfectly balanced, and friction is negligible.

Nomenclature

E_L = line voltage (volts)
E_A = armature-circuit voltage (volts)
I_F = field current (amperes)
ϕ_T = field flux induced by I_F (maxwells)
ϕ = field flux effective on armature in gap (maxwells)
N = number of turns on field coils
K = spring constant of spirals (millimeter grams per radian)
K_1, K_2, K_3, K_4, and so forth = constants
I_a = current in armature circuit (amperes)
Z_a = impedance of armature circuit (ohms)
X_L = inductive reactance of armature circuit (ohms)
X_C = capacitive reactance of armature circuit (ohms)
L = inductance of armature circuit (henrys)
C = capacitance in armature circuit (farads)
R_a = armature-circuit resistance (ohms)
S = initial deflection of spiral springs from center scale (radians)
θ = armature deflection (radians) (+ is clockwise). When $\theta = 0$,

(a). Pointer is at center scale.
(b). Spiral deflection is $+S$.
(c). Armature vane is in line with flux ϕ.
(d). Armature winding axis is at 90 degrees to flux ϕ.

y = moment arm of armature conductors
f = frequency, cycles per second
T_D = electrodynamic deflecting torque (millimeter grams) (+ is clockwise)
T_V = torque due to armature iron vane (millimeter grams) (+ is clockwise)
T_S = torque due to spirals (millimeter grams) (+ is clockwise)
α = phase angle between armature voltage and current
$\alpha = \tan^{-1}[(X_L - X_C)/R_a]$

Analysis

The electrodynamic deflecting torque, T_D, acting on the armature of the frequency instrument is

$$T_D = K_1 \phi y I_a \sin \alpha \qquad (1)$$

The flux, ϕ, in the air gap of the instrument due to the field current, I_F, which reacts with the armature current, I_a, may be expressed as

$$\phi = K_2 \frac{E_L}{fN} \qquad (2)$$

The component of the armature current, I_a, which is in phase with the field flux, ϕ, is

$$I_a \sin \alpha = \frac{E_a}{Z_a} \sin \alpha \qquad (3)$$

The moment arm of the armature conductor may be written

$$y = K_3 \cos \theta \qquad (4)$$

Equations 2, 3, and 4 may be substituted in equation 1:

$$T_D = K_4 \frac{E_L E_a}{f N Z_a} \sin \alpha \cos \theta \qquad (5)$$

A Distance Relay With Adjustable Phase-Angle Discrimination

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MEMBER AIEE

DISTANCE-TYPE transmission-line relays have been used very successfully for a number of years. Several different distance-type characteristics have been available. Among these characteristics are the impedance relay which measures impedance substantially independent of the phase angle, the reactance relay which responds only to the reactive component of the impedance, and a third characteristic which responds to a compromise between pure impedance and reactance. Another type of relay characteristic which combines impedance measurement with a directional indication has been used for a number of years as a fault-detector element to supervise another distance-measuring element.

These distance-type relays have been able to cope with most of the conditions encountered on the majority of transmission lines and systems. However, at present, the conditions which the relays must handle are becoming more and more difficult. This is because of increased loading especially on the longer transmission lines. Because of this it is becoming increasingly difficult for distance relays to distinguish between fault conditions and load conditions. It is the purpose of this paper to describe a new relay whose distance-response characteristic can be shifted or moded to fit different conditions. Distance elements which have capacity to discriminate between load currents and fault currents have been available but have been used mostly as fault-detector elements rather than distance-measuring elements to provide primary protection.

The relay to be described has directional discrimination as well as distance-measuring capacity and furthermore its directional discrimination can be regulated from zero to the maximum by the manipulation of suitable taps.

In applying relays to a transmission system it is necessary to state the relay characteristics in the same terms that the system conditions are stated. This is especially true of distance-type relays. If the relay characteristics are thought of in terms of volts and amperes, then the system conditions should be stated in the same terms. With the distance relays, however, it is difficult to think in terms of volts and amperes, because these values vary widely for the same relay response. This relay response is some function of the ratio between volts and amperes and, for any given value of the ratio, there may exist an infinite number of values of the volts and amperes. It therefore simplifies matters greatly to think of the distance-relay response in terms of the ratio of volts to amperes or in other words to think of the impedance, reactance, resistance, or combination thereof to which the relay responds. In applying these relays to a power system it is necessary to think of the system in the same terms. However, in designing distance relays it is necessary to think in terms of the volts, amperes, and phase angle to which it must respond because these are the quantities which actually operate the contact-actuating parts.

When distance relays are applied to transmission lines it is most convenient to plot both the relay characteristics and the transmission line conditions on an impedance diagram, that is, on rectangular co-ordinates of resistance and reactance. This gives a picture of the impedance values for which relay operation is desired, as well as a picture of the impedance values seen by the relay during load and synchronizing surge conditions, for which operation is not desired.

It is interesting to see what the various relay characteristics look like on a current-phase angle basis and what occurs when transfer is made to the R and jX diagram. When the current response against a given voltage is plotted against phase angles, the loci of all distance-type relays whether impedance, reactance, resistance, or any combination thereof are circles if we consider the straight line as the special case of a circle with infinite radius. No attempt here is made to provide rigorous proof of this statement as this has been covered in various publications. It is instructive to examine the various distance-relay characteristics on the current-angle diagram and then transfer them to the resistance and reactance co-ordinates.

With reference to Figure 1, the impedance relay has the response circle shown with its center at the origin. It is obvious that the current locus must be a circle since a pure-impedance relay will operate against a given voltage restraint at the same current value regardless of the phase angle between the current and voltage. To transfer this circular characteristic to the resistance-reactance co-ordinates in Figure 2, it is necessary only to divide the constant-voltage restraint by the current pickup values at different angles and plot the resultant impedance

---

The restoring torque acting on the armature due to its iron vane tending to align itself with the field flux, ϕ, is

$$T_V = -K_3\left(\frac{E_L}{fN}\right)^2 \sin 2\theta \qquad (6)$$

The extraneous torque due to the lead-in spiral springs is

$$T_S = -K(\theta+S) \qquad (7)$$

Since the summation of torques acting on the armature must be zero, for steady-state indication,

$$T_D+T_V+T_S=0 \qquad (8)$$

If equations 5, 6, and 7 are substituted in equation 8:

$$K_4\frac{E_L E_a}{fNZ_a}\sin\alpha\cos\theta - K_3\left(\frac{E_L}{fN}\right)^2\sin 2\theta - K(\theta+S)=0 \qquad (9)$$

This is the equation for the scale distribution. For the purpose of determining the values of K_4 and K_3, the following boundary conditions are assumed which correspond to the scale length of one of the sample instruments:

1. At $f=350$ cycles the pointer deflection is $\theta=-44$ degrees.
2. At $f=450$ cycles the pointer deflection is $\theta=+43$ degrees.

By substituting these values and the known constants, equation 9 is reduced to the following functions of frequency and deflection:

$$(2.4)10^6\frac{\sin\alpha\cos\theta}{fZ_a}-(1.56)10^4\frac{\sin 2\theta}{f^2}-0.038(\theta+1)=0 \qquad (10)$$

Equation 10 defines the theoretical scale distribution in terms of pointer deflection, θ; frequency, f; and known constants. The solution to equation 10 is shown by the calculated curve of Figure 14 and is compared to the distribution of one of the sample instruments by the "actual" curve. Deviation between the curves is due mostly to the nonuniform distribution of flux in the air gap.

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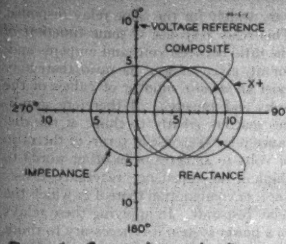

Figure 1. Current–phase-angle diagram of impedance, reactance, and composite characteristics

values at the corresponding angles on the R–X diagram. Obviously the current circle of Figure 1 with its center at the origin is also an impedance circle in Figure 2 with its center at the origin. If the current circle, Figure 1, were to be moved to the right along the 90–270-degree axis until it is tangent to the 0–180-degree axis it then becomes a pure reactance characteristic. Plotting the reciprocal of the current-pickup values given by this circle at different angles on the R–X diagram at corresponding angles gives the straight-line reactance characteristic in Figure 2. Placing the circle at a position between the impedance and reactance circles in Figure 1 gives a composite characteristic depicted by the large circle in Figure 2. Pushing the circle in Figure 1 beyond the reactance circle such as at $X+$ bends the reactance characteristic in Figure 2 upward into the circle shown.

While in the foregoing discussion the characteristic circle was shifted along the X axis, it is to be understood that this shifting process can be performed along any angular axis.

In Figure 1 the current-locus circle

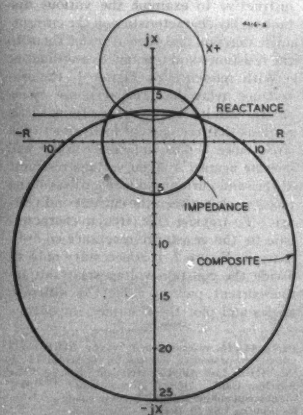

Figure 2. Resistance–reactance diagram of current loci of Figure 1

was shifted to the right by bodily moving the circle over. The circle can be shifted in another manner, that is, by holding a point on the circle stationary and then expanding its diameter to minus infinity after which its diameter is reduced from positive infinity. Figure 3 shows this transformation where the circles are all passed through the point $I=5$. Transferring these circles to the R–X diagram yields the interesting set of circles in Figure 4. Note that the impedance circle decreases in diameter and moves upward. The movement of the center of the circle away from the origin means that the impedance characteristic acquires a sense of direction. In other words, it means that response to impedance values in some directions is greater than its response in other directions. When the circle becomes tangent to the R axis, it

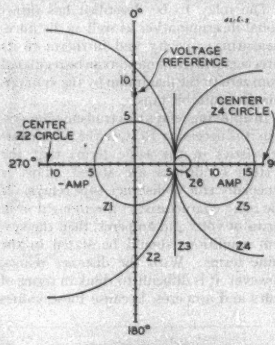

Figure 3. Current–phase-angle diagram of various impedance characteristics

means that the impedance characteristic has become completely directional.

In applying distance relays to transmission lines it is convenient to plot the conditions for which tripping is desired as well as the nontripping conditions on resistance and reactance co-ordinates. It is easy to plot the fault ohms on this diagram as the resistance and reactance ohms of the transmission line are readily available. Thus in Figure 5 the line L_T–L_T' represents the line on which the impedance ohms of the line fall, and the point B represents the ohms for a solid fault at the far bus. The vector L_{TR} represents the apparent impedance value when fault arc resistance is included. On short lines the line ohm vector is the only one to be considered. However, on the longer heavily loaded lines it is usually necessary to consider the impedance values seen by the relays during normal load conditions and during surge conditions when synchronizing current is flowing over the line to keep the generating sources in step. While it is easy to plot the normal-load-impedance vector it is generally much more difficult to plot the values representing momentary load swings and synchronizing surges. The exact location of the impedance vectors for the latter conditions involves considerable calculation but methods for doing this have been covered previously. An approximate idea of the manner in which the synchronizing-surge-impedance vector shifts can be gained by locating the point along the line L_T which represents the number of ohms the electrical center is away from the relay location. The load or surge-impedance vector will terminate in a straight line which intersects the line L_T at the electrical center. The more severe the swing condition the closer this vector will approach the line L_T. Some particular maximum approach to the line L_T will represent the dividing line between ability of the system to stay in step or to develop into a definite out-of-step condition. Generally it is desirable to permit tripping for all surge conditions from which the system cannot recover but to prevent tripping for all load conditions and surges up to this nonrecovering point. The object in applying distance relays to transmission lines is to utilize a relay characteristic that will trip definitely for faults on the line but not trip for swing conditions from which the system can recover. This means that the relay-response characteristic, when plotted on the R–X diagram, must encircle properly the line ohms including fault resistance but must not encircle the swing ohms. Realizing that the minimum synchronizing surge ohms for which it is not desired to trip may fall quite close to the fault-ohm line it becomes evident that a characteristic similar to Figure 5 is necessary. Such a characteristic could enclose the line ohms but exclude the synchronizing-surge ohms if the diameter of the circle, the position of the circle on an axis, and the angular position of the axis were all adjustable.

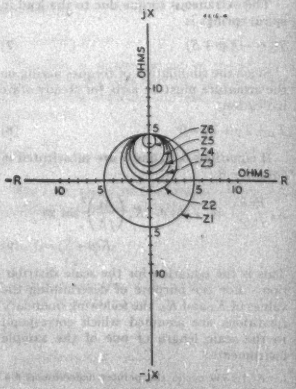

Figure 4. Circles of Figure 3 plotted on R and X co-ordinates

Such a characteristic has been imparted to the beam-type impedance relay by making the restraint proportional not to voltage alone but proportional to the vector sum of the fault voltage and the fault current while the operating force is made proportional to the fault current. Figure 6 shows the schematic connections. The delta current I_A–I_B is applied to the primary winding of a current transformer and to the operating coil on the beam element. The secondary of the current transformer being shunted by the reactor X_c causes a voltage drop across the resistor R_t which leads the current by 60 degrees. A portion of the voltage R_t is introduced into the circuit supplying voltage to the standard split-phase potential-restraint coils of the beam element. The voltage E_{AB} is fed through the phase shifter as shown. As a result of this arrangement the energy fed into the potential-restraint coils of the impedance element is proportional to the vector sum of E_{AB} and I_A–I_B.

The action which takes place to cause the element to have a circular characteristic can be seen from the vector diagram in Figure 7. This is drawn for the case where the center of the circle is to be placed on the X axis and the circle is to pass through zero. Assume that the fault current I_A–I_B=I_R lags the fault voltage E_{AB} by 90 degrees and that under this condition the current in the potential-restraint coils due to the fault current I_R is 180 degrees out of phase with the current due to the restraint voltage E_{AB}.

The operating energy on the front end of the beam is represented by the vector I_0, although this is the same current as that operating on the rear end of the beam, while the current on the front end is shown as a vector, no vector relationship exists between the pull on the front end and the pull on the back end of the beam, since the beam has substantially no response to the phase angle between the forces on the two ends. It is arranged that the current I_0 produces a mechanical force on the front end of the beam equal

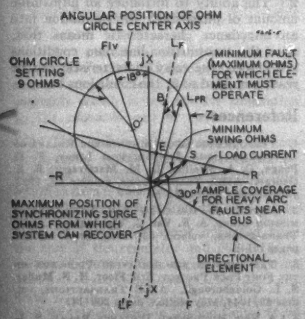
ANGULAR POSITION OF OHM CIRCLE CENTER AXIS
OHM CIRCLE SETTING 9 OHMS
MINIMUM FAULT (MAXIMUM OHMS) FOR WHICH ELEMENT MUST OPERATE
MINIMUM SWING OHMS
LOAD CURRENT
MAXIMUM POSITION OF SYNCHRONIZING SURGE OHMS FROM WHICH SYSTEM CAN RECOVER
30° AMPLE COVERAGE FOR HEAVY ARC FAULTS NEAR BUS
DIRECTIONAL ELEMENT
-jX
F
R
-R
jX

Figure 5. Line and relay characteristics plotted on R and X co-ordinates

to the force produced by the current on the back end of the beam when no voltage is present. For fault currents lagging 90 degrees it is easy to establish the conditions for a balance point. For instance, if the voltage E is assumed to be 12 units, then it is evident that the current I_R directly opposite must be 6 units in order for the net restraint of 6 units just to balance an operating force of 6 units. If the current lags the voltage less than 90 degrees (say I_R'), it must be increased to a value such that the vector sum of I_R and E_1 (or I_1) still equals I_R because the operating current I_0 has increased at the same rate, in order to maintain a balance point. It can be seen from an inspection of Figure 7 that the current I_R and I_0 for any angle must terminate on the straight line MM in order to make the scalar value of the vector sum E_1+I_R=I_1=I_R=I_0. In other words, the line MM represents the locus of balance currents for a given voltage E_1. Division of the voltage E_1 by the balance currents gives

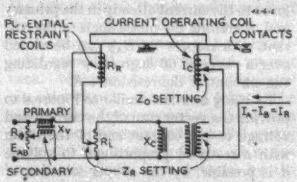

Figure 6. Schematic connections of impedance relay with adjustable characteristics

impedance values, which plotted on R and X co-ordinates gives a circle with its center on the X axis and passing through zero. The pull of the current on the restraint end of the beam must be equal to the pull of the current on the other end in order for the current locus to become a straight line. If the current pulls do not balance the characteristic becomes a circle above or below the straight line depending upon which way the beam is unbalanced so that on current alone one unit of I_0 is required to balance two units of I_R (or I_0=$2I_R$), and the characteristic becomes a circle as shown. Under this condition one balance point with voltage applied will be when 12–I_R=I_0=$2I_R$ or I_R=4 units. The other balance point is given by I_R–12=I_0=$2I_R$ or I_R=–12. On the R and X diagram this is a circle with its center on the X axis and the origin is within the circle. If I_0=$I_R/2$, that is, the current on the restraint end of the beam is predominant, then we obtain the circle shown which on the R and X diagram does not contain the origin.

It is clear from the foregoing that the introduction of current into the voltage-restraint circuit has performed the circle inversion depicted in Figures 3 and 4. However, in these figures the current circle was inverted by holding a point on its periphery fixed. This caused the im-

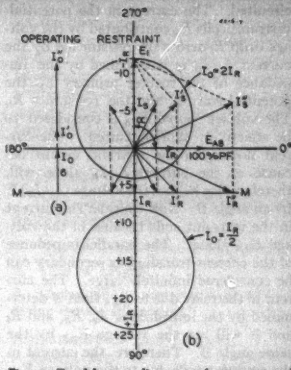

Figure 7. Vector diagram of current and voltage forces acting on the beam

pedance circle, Figure 4, to diminish in diameter as it was shifted. It is, of course, desirable that the impedance-circle diameter remain constant while the center is shifted. The arrangement shown in Figure 6 accomplishes this purpose. The location of the circle on the R and X diagram is dependent upon the ratio of I_0 to I_R while the radius is dependent only upon I_0. Figure 8 has been drawn for different ratios of I_0 to I_R and is similar to Figure 3 except that the circles do not go through a common point. Figure 9 shows these coils transferred to the R and X diagram. The displacement of the R and X circle with constant diameter to infinity corresponds to the disappearance of the current circle at the origin when I_R is made infinitely large compared to I_0.

The circuit shown schematically in Figure 6 provides independent adjustment of the diameter of the impedance circle, its location on an axis, and the angle of the axis. The following considerations will bring out the method of accomplishing these adjustments. Consider for the moment that the reactor X_c and the secondary of the reactor X_t are open-

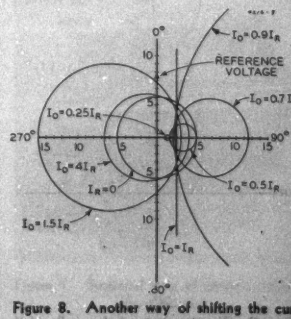

Figure 8. Another way of shifting the current-phase-angle circles to keep impedance circle radius constant

circuited. The current in the potential-restraint coils R_B contributed by the voltage drop R_t across the resistor fed by the current I_A-I_B is determined by the impedance of the reactor primary Z_r, the potential coil R_B, and the resistance R_t. The voltage source E_{AB} is considered to be effectively short-circuited. The current flowing in the restraint circuit because of the current I_A-I_B alone will, therefore, lag behind the voltage $(I_A-I_B)R$ by an angle B. Now consider the current in the restraint coils because of the voltage E_{AB} alone. The parallel impedance of the current-transformer secondary can be considered infinitely large. The current in the relay due to E_{AB} then is determined by the impedances Z_r, R_B, and R_t and it will lag the voltage E_{AB} by the same angle B. Therefore, the current in the restraint coils due to the voltage E_{AB} and the current I_A-I_B will be in phase or 180 degrees out of phase when I_A-I_B is in phase with E_{AB}. Now consider what is necessary to place the characteristic circle on the R and X diagram so that its center is on an axis 60 degrees lagging the R axis and so that the circle passes through the origin. From Figure 7 it is seen that an R and X circle passing through the origin requires a straight-line current locus as shown. Also note that the straight-line locus always occurs perpendicular to the current in the restraint coils contributed by the fault current I_A-I_B when this current is directly opposite to the current in the restraint coils produced by the voltage E_{AB}. These two currents are directly opposite when I_A-I_B is in phase with E_{AB} as was just shown. Therefore, if the voltage across the resistor R_t is caused to lead I_A-I_B by 60 degrees the direct opposition of voltage and current ampere turns in the restraint coils will occur when the fault current I_A-I_B lags E_{AB} by 60 degrees thus placing the R and X circle on the 60-degree axis. The circle, of course, is made to pass through

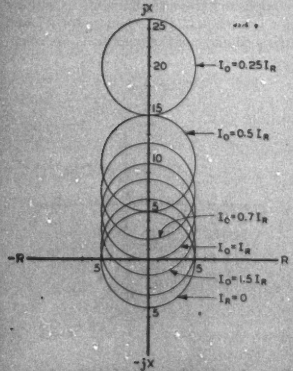

Figure 9. The impedance circles on *R* and *X* co-ordinates resulting from Figure 8

the origin by making the pull of the current I_O on the operating side of the beam just balance that of the current I_B on the restraint side. This is done merely by regulating the number of turns and core-screw setting on the impedance element and the turns on the transformer primary and the tap on the resistance R_t. For complete flexibility it is desirable to be able to shift the axis along which the characteristic is to be moved to a maximum of 120 degrees. This means that when the fault current I_A-I_B lags the fault voltage E_{AB} by 120 degrees the current and voltage energizations in the restraint coils must be in direct opposition. Since the current in the resistor R_t was advanced in phase a fixed amount of 60 degrees by adding the shunt reactor the only way to obtain 120 degrees is to lag the current in the restraint coils due to the voltage E_{AB} by 60 degrees. This is done by passing a current through the secondary winding of the reactor X_s in phase with E_{AB} because of the resistor R. This adds a component of current almost at 90 degrees to the current already in the primary and, therefore, the phase angle of the current with respect to E_{AB} can be varied over a range of 60 degrees by regulating the amount of the resistance R.

By using a circuit similar to Figure 6 to provide the vector sum of the current and voltage to the contact end of the beam with a restraint proportional to voltage it is possible, by the proper selection of constants and phase shifts, to produce the type of characteristic depicted in Figures 1 and 2. This was covered in a paper before the Institute several years ago.

Course adjustment of the center of the circle is provided by the primary taps on the current transformer while continuous adjustment between taps is provided by a slider on the resistor R_t. The diameter of the circle is controlled by the standard tap and core-screw (*TS*) adjustment on the impedance-element current coil. The axis of the circle is rotated by adjustment of the resistor R_ϕ. All of these adjustments are entirely independent and anyone can be changed without affecting the others.

It becomes evident that a relay with such a flexible characteristic materially aids in the problem of avoiding tripping on load currents and synchronizing currents without jeopardizing the ability to trip faults. With reference to Figure 5, the circle *Z2* is an example showing how the characteristic can be placed so that the fault ohms L_{FR} can be included in the circle and still have the much shorter synchronizing-surge vector fall outside the tripping zone.

Figure 10 shows the range over which the new relay characteristic can be adjusted. The current-transformer primary and resistor setting R_t are calibrated in ohms (Z_R) and when $Z_R=0$, the center of the characteristic circle is at the origin or in other words the characteristic is pure impedance without directional dis-

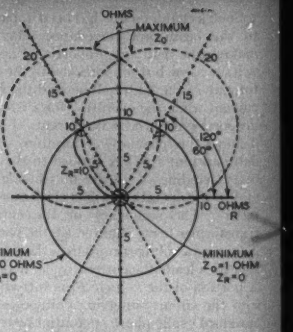

Figure 10. Range of adjustment of impedance characteristic of new relay

crimination. The radius of the circle is determined by the tap and core-screw setting on the beam-current coil. For any value of the radius the center of the circle can be shifted up the axis by the setting Z_R without changing the radius of the circle. The circle can be shifted in the opposite direction merely by reversing the polarity of the current or voltage. In addition to this the axis on which the circles are shifted can be rotated between 60 degrees and 120 degrees lagging in steps of 12 degrees by adjusting R_ϕ.

The adjusting network is housed in an external case there being three networks in each case so that each distance element of the standard three-zone impedance relay can be adjusted. Furthermore, the relay (type *HZM*) and the external adjusting case are arranged so that the characteristic of either one, two, or three distance elements of the relay can be supplied with the modified characteristic.

Conclusions

1. The utilization of the vector sum of the current and voltage on the operating or restraint side of a beam-type distance relay makes it possible to impart any type of circular characteristic whatsoever to the distance element.

2. The ability to introduce an adjustable amount of phase-angle discrimination into an impedance characteristic means that, once the transmission-line ohm conditions are known, the relay characteristic can be readily molded to fit the conditions best

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Carbon-Pile Voltage Regulators for Aircraft

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NONMEMBER AIEE

WITH the increase in size of modern military aircraft and the complexities of its equipment, it has been necessary to enlarge greatly its electric system. Up to the time of the beginning of the second World War in Europe, the Tirrell and step-type regulators were used universally to regulate the voltage of aircraft generators, alternators, and motor generator sets. With the coming of lightweight 30-volt 100- and 200-ampere generators, the field current required began to exceed the limitations of the Tirrell regulator. It became apparent that a high-field-current voltage regulator would have to be developed since the appreciable weight saving gained by designing generators with high field currents is so vital to modern aircraft.

This requirement was met by adapting the well-known art of carbon-pile regulation, long-used in railroad lighting equipment, to aircraft. It is the purpose of this paper not to dwell too deeply on the actual design features of the regulator itself, but to acquaint the reader with a general knowledge of its principle of operation, and to discuss its advantages and disadvantages and its numerous applications.

General Construction

Figure 1* shows a sectional view of a conventional present-day carbon-pile regulator, and Figure 2 shows the same regulator not sectionalized. Close examination of Figure 1 discloses that the regulator consists primarily of

(*a*). An ironclad magnetic circuit enclosing a controlling solenoid and an adjustable core.

(*b*). An armature assembly which is mounted on radial leaf springs with a center contact plug insulated from the armature assembly which is the electric connection to the movable end of the carbon pile.

(*c*). The carbon pile consisting of precision-made carbon disks surrounded by and held in place by an insulating tube which in turn is enclosed by a finned housing for dissipating the heat from the carbon pile.

(*d*). An adjustable screw insulated from the rest of the regulator and containing a carbon button. This screw and button acts as the contact for the stationary end of the carbon pile.

Other details of Figure 1 show the regulator proper mounted on a quickly detachable mounting base on which is mounted a fixed resistor and a variable rheostat for raising or lowering the regulated voltage.

Principle of Operation

When the solenoid is unenergized, the armature is pushed against the carbon stack by the springs, thus compressing the carbon pile so that its resistance is at its very minimum. Energizing the solenoid causes the armature to be magnetically attracted to the ironclad magnet case. Magnetic force acts in the opposite direction to the spring force. The compression force exerted on the carbon pile is the difference between the spring force and the magnetic force. It is this varying magnetic force, created by the solenoid, that tends to overcome the spring force and thus vary the pressure on the carbon pile, and hence its resistance. Any change in the resistance of the carbon pile directly effects the output of the machine whose voltage is being regulated, which in turn tends to raise or lower the voltage across the solenoid. Since the regulator is extremely sensitive to any change of *NI* in the solenoid, a balance of magnetic and physical forces takes place in the regulator, and regulation becomes automatic.

Temperature compensation is obtained by the proper selection of the resistance ratio in the coil circuit and by matching a bimetallic spring support to the expansion characteristic of the regulator. Total resistance of the coil circuit consists of copper resistance and an external near-zero-temperature-coefficient resistance connected in series. The bimetal has a slight angle on which the armature springs rest. With an increase in temperature, the bimetallic washer tends to flatten out or the angle decreases. In this way the pressure exerted by the springs lessens. This in turn compensates for the decrease in the magnetic pull resulting from the heating of the copper solenoid coil and other parts affected by temperature. Present-day regulators are temperature-compensated to give satisfactory voltage regulation at ambient temperatures ranging from −50 to +71 degrees centigrade.

Adjustment of the Regulator

Three separate adjustments are provided in the regulator:

1. Coil-circuit resistance or coil-current.
2. Core or air-gap.
3. Carbon-pile compression-screw or spring-tension adjustment.

Adjustment of Coil-Circuit Resistance

Coil-circuit resistance is set by means of the adjustable resistor or rheostat to a value predetermined by the manufacturer. In cases where adjustable rheostats are used, the resistances are so chosen that the contact slider arm will be set in the middle of the rheostat resistance range. This will permit a raising or lowering of the regulated voltage after the regulators have been adjusted properly and put into service. Once the coil-circuit resistance has been set, it should not be changed throughout the remainder of the adjustment procedure since the proper *NI* in the solenoid in this way has been fixed for a given regulated voltage. Also, a proper resistance ratio is established to give good temperature compensation.

Preadjustment of the Core

When the regulator is first assembled at the factory, the core is screwed in until its face is just flush with the face of the magnet case next to the armature assembly. At this point the core is center-punch-marked at the adjustment end, and a corresponding center-punch mark is put on the end plate. In this way, it is possible to line up the two cen-

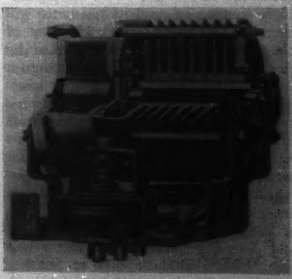

Figure 1. Sectional view of modern carbon-pile regulator

This unit regulates d-c generator output for both single- and parallel-generator systems

* The regulator, as shown in Figures 1, 2, and 4, is of the type disclosed in Newton United States patent 2,268,718 under which the United States Government holds a nonexclusive license for the duration of the war.

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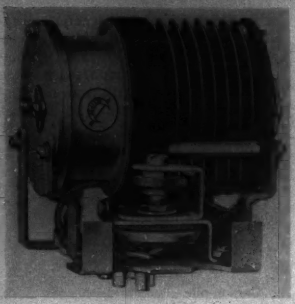

Figure 2. Same unit as shown in Figure 1, except not sectionalized

This carbon-pile voltage regulator is for use in conjunction with single-voltage generators rated from 1.5 to 12 kw

ter-punch marks after the entire regulator has been assembled and thus set the core flush with the magnet case. Correct set position of the core should be such that the core air gap is slightly greater than when set in the flush position.

Adjustment of Pile Compression Screws

With the regulator adjusted as already indicated, the carbon pile should be connected in series with the control circuit of the unit whose voltage is to be regulated and the coil circuit connected across the output. Run the unit so that it would normally produce its rated output if the regulator were properly set. For the purpose of illustration, assume that the carbon-pile compression screw is just turned in to the point at which the contact plug makes contact with the carbon pile. As the pile compression screw is turned in, the entire armature assembly will be moved toward magnet case, increasing the spring tension and decreasing the air gap between the armature and core. Increasing the spring tension will cause the carbon pile to be correspondingly compressed, and its resistance will decrease. Continued inward motion of the pile compression screw will cause the regulated voltage to rise to a maximum point *B*, (Figure 3), decrease to a minimum point *D*, and then increase very rapidly from *D* to *E*. From *A* to *B* and from *E* to *F* (Figure 3) the unit fails to function as a regulator, but acts as a manual carbon-pile rheostat. In the region of the curve from *B* to *E* the unit acts as an automatic carbon-pile rheostat or regulator. However, between *B* and *C* on the curve, the regulator will pass through an instability or hunting stage, becoming less and less violent and finally disappearing as point *C* is approached. It is obvious that no instability in the regulator can be tolerated at any time, as this causes the carbon pile actually to open the circuit, and a destructive arc results which burns the carbon disks, greatly shortening their life and, hence, the useful life of the regulator. Instability in the carbon pile can be detected readily by connecting a sensitive undampened voltmeter, an oscillograph or a set of earphones with at least 1,500 ohms impedance, across the carbon pile, the oscillograph and earphones being the most sensitive. Fluctuation of the carbon-pile voltage will cause the voltmeter needle to fluctuate and will cause the earphones to become very noisy. In the case of the earphones, violent instability will cause an unbearable noise as compared to a quiet hum when stable operation of the regulator is obtained. Best regulating position of the pile screw occurs between *C* and *E*. In general, a setting of the pile compression screw to the left of the minimum point *D* will give a flat or rising voltage characteristic with load as the point set nears the instability region. Likewise, a setting to the right of the minimum point *D* will give a drooping voltage characteristic with load and will be a more stable setting of the regulator. When the approximate correct setting is obtained by the pile compression screw, the regulator voltage probably will be too low. If this is the case, the regulated voltage can be raised by turning the core plug out very slowly, thus increasing the air gap. Regulated voltage is lowered by turning the core plug in, but under no circumstances should the face of the core plug be turned in beyond the flush position. After the core plug is adjusted, the compression-screw adjustment should be rechecked. This procedure should be repeated as many times as necessary until no further adjustment of either the core plug or carbon-pile compression screw is required. All locking screws should be tight. Final setting must be such that the regulator is stable under all possible operating conditions of speed, load, or input voltage, or the useful life of the carbon pile will be short. Much can be written on the regulator adjustment in specific cases, but the aforementioned procedure, in general, applies to all carbon-pile regulators. In actual cases where units are set at the factory, the violent instability region of the curve is smoothed out by lowering the input voltage or by reducing the speed, in the case of generators, to values far below that at which they normally operate. In this way it is possible to adjust the carbon-pile compression screw and follow through the curve to point *C* or *D* without any instability whatever. After the pile compression screw has been adjusted to this point, the speed or voltage may be raised and finer adjustments made without damage to the carbon pile caused by arcing between the carbon disks. All adjustments should be made only by trained personnel and with the proper equipment, as wrong adjustments result in high voltage which is disastrous to most loads.

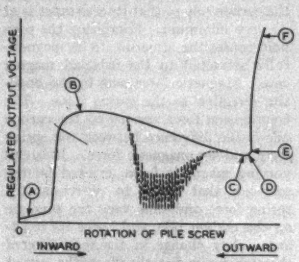

Figure 3. Effect of pile-screw rotation on regulated output voltage

If regulator becomes unstable, voltmeter needle will fluctuate rapidly, and that portion of voltage characteristic will be as shown by dotted lines in diagram. Best regulating position of pile screw is shown at *C*

Figure 4. Four different-wattage-size regulators

Left to right, 20, 35, 50, and 75 watts continuous dissipation in the carbon pile. Ratings of all can be safely raised by forced ventilation

Practical Application

At the present time, there are four different-sized regulators in production based upon the maximum continuous

wattage dissipation in the carbon pile; namely, 20, 35, 50, and 75 watts (see Figure 4).

All of the preceding can have their ratings increased greatly by forced ventilation. Although all four sizes use the same-diameter carbon disks, the lengths of the carbon piles are different. The smallest or 20-watt regulator weighs $9^1/_4$ ounces and uses a one-half-inch stack of carbon disks; the 35-watt size weighs two pounds, three ounces, and uses $1^1/_2$-inch carbon pile; the 50-watt size weighs $2^1/_2$ pounds (with base shown) and has $1^1/_2$-inch carbon pile; and the 75-watt size weighs two pounds, three ounces, and has a two-inch carbon pile. Carbon piles are available in various different carbon-disk thicknesses and grades. By varying the length, grade, and disk thickness, many different resistance ranges can be obtained. Any of the aforementioned regulators can be made to regulate different given voltages by the selection of the proper solenoid coil.

Carbon-pile regulators have been used in many different applications. For the most part, these applications can be divided into three different classifications, namely:

(*a*). Those regulating the output of engine-driven d-c generators.

(*b*). Those regulating the output of high- and low-frequency engine-driven alternators and motor-alternator sets.

(*c*). Line voltage regulators.

When used to regulate the output of engine-driven d-c generators, the generator is usually a shunt type for use on 12- or 24-volt systems, although there are cases where 115 volts d-c systems are employed as well. In all of the preceding systems, the carbon pile is connected in series with the shunt field of the generator, and the solenoid coil circuit is connected across the output of the generator.

Parallel Operation

Where generators are operated in parallel as in multiengine airplanes, each generator is made to deliver its share of the load by the use of a load-compensating coil wound as a separate winding on top of the main regulating coil in the regulator. This compensating winding is used in conjunction with a calibrated drop connected between generator negative and ground. In some cases the drop through the series winding is utilized. With the aid of an equalizer bus, if one generator carries more than its share of the load, the voltage drop will be greater in its circuit than the others.

A current will flow through its equalizer coil which will lower its voltage and hence its load and, at the same time, boost the voltage and the load in the other generators. In that way it equalizes the loads. Very little change in voltage is necessary to make the generators parallel properly, and practically no change in the bus voltage will be noted.

Other Applications

Other applications of carbon-pile regulators in conjunction with generators consist of current limiters and wattage limiters. Current limiters limit the output current of the generator to a predetermined value, usually full load plus ten per cent. Its carbon pile is connected in series with voltage-regulator carbon pile, and its coil consists of a few turns of heavy conductor connected in series with the line. When the current reaches the predetermined value, the carbon pile begins to increase its resistance, decreasing terminal voltage and limiting the output current. For the most part current limiters are not used, because modern aircraft generators are designed to carry heavy overloads without damage for the short duration of landings or take-offs.

Wattage limiters are much the same as current limiters and work the same way, except that they have an extra potential winding on the same coil as the current winding and are used where generators are driven by auxiliary gasoline engines. The purpose of this type of regulator is to limit output of generator to safe value so that excessive overloads will not stall

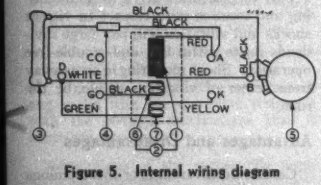

Figure 5. Internal wiring diagram

75-watt carbon-pile regulator with detachable base shown in Figures 1 and 2

1—Carbon pile
2—Regulator assembly
3—Resistor—tubular
4—Resistor—1,500 ohms
5—Rheostat
6—Coil—shunt
7—Coil—equalizer

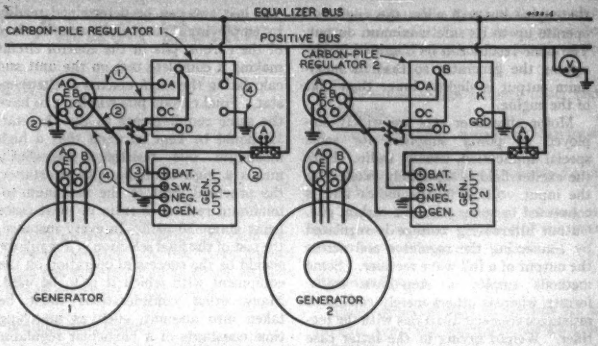

Figure 6. Typical schematic wiring diagram showing installation of M-2, O-4, and P-2 generators with carbon-pile voltage regulator

For parallel generating systems, any number of generators may be connected in the manner depicted in these diagrams, whereas for single systems generator 2 and its associated equipment and connections are omitted from the systems shown. Also to be omitted are the equalizer bus and connections to the *D* and *K* carbon-pile regulator terminals, with use of a single-pole single-throw line switch Caution: Ground (*E*, receptacle) connection of each generator in parallel system shown must provide 0.5 volt drop at full-rated generator current

Disconnect Plug Designation	Generator Circuit
A	F+
B	A+
C	Vacant
D	A−
E	A−F−

Minimum Brown and Sharpe Cable Size

Generator Type	M-2	O-4	P-2
Circuit 1	16	16	14
Circuit 2	8	4	0
Circuit 3	18	18	18
Circuit 4	16	16	16

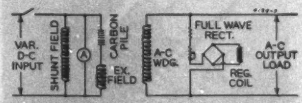

Figure 7. Motor-alternator set and regulator

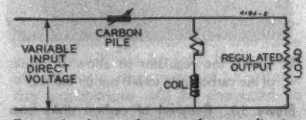

Figure 8. Line-voltage-regulator application

the engine but will allow the engine to operate up to its safe maximum output. The same results can be obtained by designing the generator so that its maximum output is slightly lower than that of the engine.

Motor-alternator sets are widely employed as power suppliers for some special application, usually radio. Here the exciter field is separately excited by the input voltage to the motor and is connected in series with the carbon pile. Output alternating voltage is regulated by connecting the regulator coil across the output of a full-wave rectifier. Some methods employ a step-down transformer, whereas others merely consist of resistance connected in series with the rectifier. Weight saving in the latter case is a large factor. Carbon-piler regulators have been used as frequency regulators in motor-alternator applications where frequency must be closely regulated. Constant frequency is obtained by regulating the speed of motor.

Line-voltage regulators are used in applications where the line voltage varies with loads, and so forth, as in the case of the electric system of an airplane, and it is desirable to maintain some value of voltage (below the minimum input variation) at a constant value. Such a load, requiring a constant input voltage, might be a filament load of radio tubes or other instruments whose accuracy depends upon its input voltage held constant. In these systems, the carbon pile is connected in series with the load, and the regulating coil circuit is connected across the load.

From what has been said, it is obvious that before selecting a regulator for a particular application, it is necessary to know

(*a*). The regulated voltage plus or minus allowable limits.

(*b*). Maximum continuous carbon-pile wattage dissipation.

(*c*). Maximum and minimum resistance.

Figure 9. Position of armature assembly and connector lead in magnet case

View shows armature assembly assembled in magnet case. Center portion is carbon button which connects to the moving end of the carbon pile

The last two can be determined readily by employing a manual rheostat in place of the carbon pile in the control circuit making a complete test on the unit and calculating the requirements of the rheostat. Final carbon pile will have to have the same requirements as the rheostat It should be kept in mind that a high maximum pile resistance necessarily means a high minimum pile resistance, the practical limit of the maximum-to-minimum resistance ratio in most cases being about 30 to 1. In every instance, the test of the final selection of a regulator should be the successful operation on the equipment with which it is to be used. Many other considerations must be taken into account, such as matching time constants of a particular regulator with the time constant of the unit with which it is to be regulated. The fact that a regulator will operate satisfactorily with one unit does not necessarily mean that it will operate properly with a unit of a different design but having the same regulating resistance requirements. Reactance voltage, commutation, and time constants all enter into the picture and must be considered. Their effect can

A. Slide a thin rod into the hold in the carbon pile and then . . . .

B. Invert the regulator to allow the disks of the carbon pile to fall out on the rod

Figure 10. Removal of carbon disks from carbon-pile regulator

A. With regulator horizontal, insert end of rod carrying disks of carbon pile into the ceramic tube then . . . .

B. Turn regulator up to a vertical position and allow the disks of the carbon pile to fall into the tube. Do not touch the disks with the fingers

Figure 11. Assembly of carbon-pile disks into ceramic tube of regulator

be determined only by actual tests.

Although the regulator is rugged in its construction and can stand much abuse, it must be remembered that it is primarily an instrument. The armature assembly has mass and is not counterbalanced (as all attempts to do so have resulted in a sluggish regulator) and is, therefore, sensitive to shocks and violent vibration. Proper consideration given to its mounting and location with respect to violent shocks and vibration will pay large dividends in its useful life, and trouble-free operation. Shock mounting in areas away from center of vibration should be the rule.

Advantages and Disadvantages

Certain disadvantages or shortcomings are experienced with the present carbon-pile regulator, as follows:

1. The regulator has three adjustments; this number will be reduced in future designs for simplification purposes.

2. Repairs and adjustments should be made by trained personnel at bases where reliable test equipment and accurate instruments are on hand.

Higher-Voltage D-C Aircraft Electric Systems

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Synopsis: Many of the advantages of 115-volt d-c aircraft electric power are presented with frequent comparisons to 24-volt direct current and 208/120-volt 400-cycle three-phase alternating current. System reliability is emphasized. Weight comparisons favorable to 115-volt direct current are shown for power generation, distribution, and load components. Problems concerning the use of the two high-voltage systems are discussed and compared. The popular belief that 115-volt d-c switching and commutation is unsatisfactory at high altitudes is refuted. It is concluded that 115-volt direct current is the lightest and most practical of the proposed electric systems for both medium and large airplanes.

CURRENT discussion of large aircraft electric systems has been carried on mainly in terms of commercial power distribution experience. There has been a tendency in such discussions to make blanket statements concerning the superiority of a-c systems without due consideration of direct current or aircraft-design requirements. Extrapolation of commercial practice and experience out of the field of its origin into aircraft design remains to be proved. The airplane presents a very special electrical design problem. Only when a-c systems are applied to actual aircraft designs, and after a careful competitive check made of both a-c and d-c results, are valid conclusions possible. A few facts learned from one such study on an actual airplane will be presented in this paper.

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Weight and Safety

Reliability and weight are the principal determinants of aircraft electrical design. These factors are far more important in aircraft than in other fields of electrical engineering. One of the large air-transport companies has estimated the value of weight saved over a five-year operating period at $600 per pound per airplane. In today's larger airplanes electricity has acquired many new responsibilities, such as engine controls, flight-surface controls, landing flaps, and landing gear, many of which are essential to flight. Thus, the design of the electric system may be literally a life or death matter.

The reliability of an aircraft electric system is a function of weight and engineering experience. Currently proposed higher-voltage a-c and d-c systems for large aircraft may be made equally reliable. However, the weight and accumulated experience necessary to achieve this result will be greater for the a-c than for the d-c system. Some of the proposed a-c systems have secured a favorable weight by sacrificing present standards of reliability. Any higher-voltage system which does not provide at least the same degree of safety as present low-voltage d-c systems employing main-engine-driven parallel-operated generators is not comparable and is not really suitable for aircraft application. The 115-volt d-c system herein discussed is intended to exceed considerably existing standards of reliability in order to assume the new electrical responsibilities. Basic requisites of any aircraft electric system includes such factors as:

1. Maximum system stability under high fault loads.
2. Optimum fault burn-clear characteristics.
3. Uninterrupted full-load capacity during momentary fault conditions.
4. Continuous uninterrupted full-load capacity in the event of failure of one main power source.

System Types

Three principal electric systems are at present receiving extensive design consideration:

1. The established standard 24-volt d-c system.
2. The 115-volt d-c system, which is the subject of this discussion.
3. The 208/120-volt 400-cycle three-phase a-c system which recently has received considerable attention.

If as much study, research, and development had been directed toward higher-voltage d-c aircraft power as has been applied in the past two years to a-c aircraft power, it is believed that the future standard would be the higher-voltage direct current.

On any given airplane a small amount of 400-cycle alternating current or 24-volt direct current may be required, but this does not constitute a significant factor in the design of the main power generation and distribution system.

Functional Breakdown of the Electric System

For the purposes of this discussion the aircraft electric system is functionally separated into three general divisions: (1) distribution, (2) generation, and (3) the load component parts.

The weight of the load component parts of an aircraft electric system is the least effected by the voltage or type of system employed. Thus for a given airplane the total weight of the motors, lights, switches, and miscellaneous equipment may be substantially unchanged for 24-volt direct current, 115-volt direct current, or 208/120-volt 400-cycle a-c designs. While small differences in the weight efficiencies of certain items on the different systems will be apparent, the over-all total weight differences are not likely to be decisive.

The weight of the generative portions of the aircraft electric system will be lighter for 115-volt than for 24-volt direct current, but both will be substantially lighter than comparable 400-cycle a-c designs.

The most important weight differences appear in the distribution system. Large

3. A minimum resistance is ever present and varies with the maximum resistance with the obvious disadvantage that it never can reach zero.

Advantages of the carbon-pile regulator are as follows:

1. The carbon-pile regulator is capable of regulating high currents.
2. The carbon-pile regulator does not contain any movable contacts to get out of order. These were always a source of trouble due to short life, causing radio interference, susceptibility to high altitudes, and a constant maintenance problem. When properly adjusted, the carbon pile gives a smooth change in resistance.
3. There are practically no moving parts to wear out or get out of order. The only parts requiring replacement are the carbon pile and contact plugs. With the proper replacement of these parts and readjustment, the regulator is as good as new.

Few people can realize what an important part in our war effort this amazing instrument performs. Its true value probably will not be fully known until after the war, when many of its present-day applications will be converted to peacetime use to make commercial aviation safer.

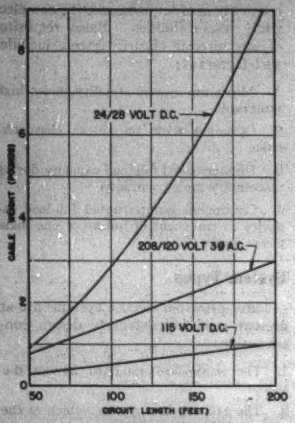

Figure 1. Aircraft cable weight for transmitting one-fourth horsepower

savings in weight with respect to low-voltage direct current are effected by both of the high-voltage systems; however, the 115-volt d-c distribution system is by far the lightest.

Degree of Electrification

Weight analyses for the three electric systems is difficult because of the large variation possible in the degree of electrification in airplanes of the same general type and size. The weight differences between the three systems vary greatly depending on whether or not heavy load items, such as landing gear, landing flaps, flight-control boosters, engine and ventilation controls are electrically operated. Electric-system designs for the same airplane may have a three-to-one variation in weight due to the degree of electrification.

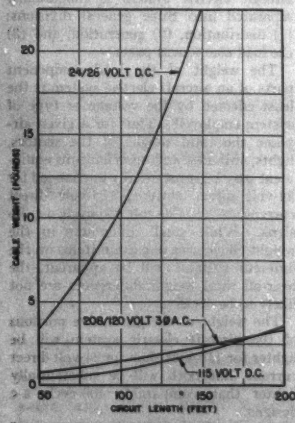

Figure 2. Aircraft cable weight for transmitting one horsepower

In present 24-volt airplanes the large variation in degree of electrification is because, in many designs, there is no decisive weight advantage for either electricity or hydraulics. However, with higher voltage the weight advantage of electric operation may be large because of the saving in wiring weight, particularly on the large airplanes. On such airplanes the wire weight to an item at 24 volts frequently exceeds the weight of the item itself.

Power Distribution

Weight Savings of 88 Per Cent

The weight for transmitting one horsepower 100 feet over a single-wire-grounded aircraft system with a five per cent allowable voltage drop, or 50 feet over a two-wire circuit, amounts to ten pounds with 24-volt direct current but amounts to less than one pound with 115-volt direct current. Figures 1, 2, and 3 show the relation between weight, distance, and horsepower for the various systems. On large airplanes much of the heaviest wiring, that from main engine-driven generators located in the wings, propeller feathering pumps, empennage turret guns, rudder and elevator boosters, landing flaps, and landing gear can be reduced to 12 per cent or less of its present weight by changing from 24 to 115 volts.

Conductor Weight

Voltage is the principal factor determining the weight of the distribution system. Metallic conductor weight in a d-c system varies with respect to voltage:

1. Inversely as the square of the voltage for those conductors determined by voltage drop.

2. Inversely as the voltage for conductors determined by current carrying capacity.

Reduction in cable weight can be carried only as far as the minimum conductor gauge (at present number 22). Thus, a change from 24 to 115 volts can result in a weight reduction inversely proportional to the square of the voltage for wires originally number 10 gauge or larger. Smaller wires, determined by voltage drop, will be reduced to the minimum size before a 16 to 1 weight reduction can occur. Similarly, a reduction to one fourth of the 24-volt-system weight, for conductors determined by current carrying capacity, will be limited to number 16 gauge and larger.

Cable Insulation Weight

The insulation of some aircraft cables appears to be adequate for any of the higher-voltage systems now under consideration. In terms of voltage change the conductor insulation weight varies:

1. Inversely as the voltage for wires determined by voltage drop.

2. Inversely as the square root of the voltage for wires determined by current carrying capacity. Cable insulation weight varies with wire size from ten per cent of the total cable weight for number 00 to 50 per cent for number 22.

Conduit Weight

Voltage, as it affects cable size, is also a major factor in determining the weight of many other accessories, such as, cable terminals, splices, connectors, junction boxes, and conduit. In terms of voltage, conduit weight will:

1. Vary inversely as the voltage for cables, the sizes of which are determined by voltage drop.

2. Vary inversely as the square root of voltage change for cables determined by current carrying capacity.

3. Not vary for instrument and other cables already containing minimum-size conductors.

Examples of 24-Volt Weight Inefficiency

A weight analysis of the 24-volt electric system of a 50,000-pound gross-weight four-engine transport indicated that:

1. Seventy-five per cent of the total conductor weight was determined by the five per cent voltage-drop limitation.

2. Five per cent of the total conductor weight was determined by current capacity limitations.

3. Twenty per cent of the total conductor weight was not affected by voltage change.

4. Seventy per cent of the total cable weight was estimated to be metallic conductor, and 30 per cent to be insulation.

Thus the weight efficiency of the 24-volt d-c system is poor even on present airplanes. In the example just cited only seven per cent of the conductor weight of cables larger than minimum size was operating at maximum current carrying capacity. Even two-engine airplanes in the 20,000-pound gross-weight class will have less than 50 per cent of the conductor weight of cables above minimum size operating at maximum capacity. For good weight efficiency it is desirable that aircraft electric-system voltage be high enough, so that substantially all of the wiring is either operating at maximum current carrying capacity or is reduced to the minimum allowable size.

In designing 24-volt electric systems for some of the really large airplanes now under construction with gross weights of several hundred thousand pounds, it is found that less than one per cent of the conductor weight of cables above minimum size would be operating at maximum current carrying capacity. It is believed that the magnitude of the weight penalty paid for use of present 24-volt aircraft

electric systems is not generally appreciated. On the four-engine transport airplane previously mentioned it was estimated that more than 100 pounds of wiring alone could have been saved by designing for 115-volt direct current.

The wiring-system weight of one large eight-engine airplane was calculated for two different designs. With a maximum degree of electrification the electric cable and bus weight totaled 2,190 pounds for 24-volt and 906 pounds for 115-volt direct current, a saving of 1,284 pounds. With a minimum degree of electrification the electric conductors had a total weight of 1,100 pounds for 24 volts and 600 pounds for 115 volts, a saving of 500 pounds.

Comparison of A-C and D-C Cable Weight

Actual design figures indicate that three-phase a-c power-distribution systems will weigh considerably more than comparable d-c systems for the following reasons:

1. Currently proposed a-c systems require three conductors for each three-phase circuit. Only a single conductor is needed in commonly used grounded return d-c systems. Application of three-phase a-c power to circuits already reduced to minimum size in 115-volt d-c designs will result in a three-fold increase in weight for the wiring of these circuits. Increasing the present electric system voltage approximately four times, from 24 volts to 115 volts, will reduce to minimum size more than 50 per cent of the total cable weight of even our largest airplanes of several hundred thousand pounds gross weight. While a considerable portion of this minimum-size wiring will be for single-phase lighting and instrument loads, an increase in total cable weight of 40 per cent or more can be expected from this cause when three-phase four-wire grounded-neutral a-c systems are compared with equivalent grounded-return d-c systems.

2. Power factors from 40 to 70 per cent are expected for 400-cycle motors and other inductive items. It is estimated that additional weight for power-factor correction or increased cable size will raise the total cable weight from 5 to 10 per cent.

3. Connectors, terminals, conduit, and other devices incidental to the power-distribution system, of course, will be lighter for a single-wire grounded-return d-c system than for a three-wire three-phase grounded-neutral a-c system. Roughly, the total estimated weight of these sundries for one specific design was 20 per cent more for alternating current than for 115-volt direct current.

On airplanes over a hundred thousand pounds gross weight, the weight of three-phase grounded-neutral a-c power distribution probably will exceed by 50 per cent the total weight of a single-wire grounded-return d-c system, voltages being the same. At present even the 208+120-volt three-phase wiring weight is considerably heavier than that for the 115-d-c equivalent.

In the future, when airplane designs require several hundred kilowatts of electric power, it may prove desirable to use 230-volt d-c or perhaps 230/115-volt d-c systems. While potentials higher than 115 volts have only a small weight advantage at the present time, they do introduce insulation and switching problems.

This study indicates that 115-volt direct current offers weight savings even for small airplanes of 25,000 pounds or less gross weight. This is not true of three-phase alternating current, since the relative weight disadvantage of three-phase a-c power distribution increases rapidly with decrease of airplane size.

Comparison of A-C and D-C Distribution-System Reliability

Safety of any system or device is largely a function of its simplicity. The single-wire d-c aircraft distribution system certainly achieves the optimum of simplicity. Statistically, it can be shown that protective devices, fuses, circuit breakers, and relay systems can be carried beyond the point of optimum reliability. Every protective device added to a circuit or system carries with it the failure liabilities inherent in that device.

On main distribution lines and feeders it is desirable to provide multiple fault protection within the lines. This practice has for more than a decade been used in industrial and municipal power-distribution systems. Figure 4 illustrates a simplified three-wire multiple fault-protected feeder system of familiar design. It will be noted that a fault at point X would be fed by parallel fuses A, B, C, and D in series with the faulted line's single fuses E and F. It is obvious that fuses E and F, each fed by two units in parallel, would blow, clearing the line of this fault. This type of circuit protection is of doubtful value in low-voltage systems, since contact-resistance and slight-resistance inequalities of the feeder branches will cause unequal current distribution in the feeder lines sufficient to upset the effective fault discrimination of the circuit. At higher voltages these same factors have a negligible effect on the protective action and fault discrimination of the circuit. Not only does this provide increased safety and reliability for all main feeders, busses, and essential circuits, but also, with a single-wire 115-volt d-c design little of the essential protection of this system is lost by the added complexity. The case is very different when the same type of three-wire multiple fault protection is attempted in a three-phase four-wire a-c distribution system. In such circuits the number of protective devices would be multiplied by three over those required for direct current. It is doubtful whether a three times increase in complication and circuit-protector inherent liability would result in an overall safety gain. Many essential circuits having minimum-sized wire can be protected justifiably in a single-wire d-c system.

Both safety and cost of airplane operation are affected favorably by the simplicity of the single-wire d-c distribution system. Present service and design and manufacturing personnel would have to be trained especially for the safe operation of a-c aircraft systems. The application of 115-volt d-c aircraft power would involve no essentially new techniques nor operational hazards.

Circuit-Interrupting Equipment

Design Fundamentals

Interrupting equipment for 115-volt direct current can be lighter than existing 24-volt direct current or 208-volt three-phase alternating current.

The design parameters of 24-volt direct current, 115-volt direct current, and 208-volt alternating current for aircraft switches differ radically. The widespread belief that switching of 115-volt direct current is difficult results from unsatisfactory performance of certain available 24-volt equipment when tested at 115 volts. Assertions that adequate 115-volt d-c switches will compare in size and weight with the conventional industrial counterparts are incorrect. It is also improper to expect a-c equipment to perform satisfactorily on direct current.

A low-travel snap-action-type switch, having a 0.070-inch contact gap and rated ten amperes at 24 volts direct current, interrupts less than one ampere at 115 volts direct current. Also, an *AN*-3023 aircraft toggle switch rated ten amperes at 24 volts interrupts less than one ampere at 115 volts. Actually, three amperes in a 115-volt d-c inductive circuit will support an arc across a one-eighth-inch gap. Such performance has discouraged the adoption of 115-volt d-c aircraft power. This attitude is not justified, since well-known design principles can and have been applied to solve this problem. These switch-design principles include:

1. Multiple break.
2. Deion grid.
3. Magnetic arc suppression.
4. Solid insulation arc barrier.
5. Liquid arc barrier.
6. Hermetical sealing.
   (*a*). Pressurized gases.
   (*b*). Vacuum.

Sufficient empirical data have been compiled which definitely disprove many statements made concerning switch inadequacy for the higher-voltage direct current.

115-Volt D-C Switches Are Available

For immediate application the Cutler Hammer Company offers a line of 110-

220 d-c "tool-handle" switches, which have 5-, 10-, and 20-ampere industrial ratings. Actual tests have indicated that these switches may be used at approximately half of their commercial rating for altitudes up to 40,000 feet when connected as single-pole double-break units. These switches are designed to interpose a solid insulation barrier between the contacts, which effectively suppresses the arc. For equivalent power interruption these switches are lighter than the conventional 24-volt line.

A double-pole toggle-switch type *AN*-3023 has six times the single-pole capacity when the two poles are connected in series for a double break.

Low-travel snap-action-type switches are available with magnetic-arc-suppression provisions and are rated ten amperes at 115 volts direct current for operation up to 40,000 feet. One such switch was tested with and without the magnet from sea level to 50,000 feet with various contact spacings. The capacity of the switch was increased by 400 per cent with the proper use of the arc suppressing magnet. It is possible to use a small magnet for arc-extinguishing purposes for as little as one tenth of an ounce additional weight per switch. Within the aircraft industry it has been stated that a magnetic field is ineffective as an arc suppressing agent at low pressures, and that arc reversal occurs at certain altitudes. A careful check was made under altitude simulated conditions up to 50,000 feet. All of the mentioned altitude irregularities of devices incorporating magnetic arc suppression were experienced, but on investigation proved to be due to inadequate insulation and spacing. The tests performed indicate that accepted theories of arc behavior in magnetic fields are correct.

The 24-volt type *AN*-3022 aircraft toggle switch may be used safely for three-fourths of an ampere at 115-volts direct current for altitudes up to 50,000 feet. At 115 volts this is 90 watts, and the switch should satisfy more than 40 per cent of the total switch requirements.

A study of airplane switching requirements indicates that 90 per cent of the loads on a large airplane will require a three-ampere switch for 115 volts and a 15-ampere switch for 24 volts.

Three-Phase A-C Switching

The three-pole switch for three-phase alternating current is inherently heavier and more complicated than the single-pole switch commonly used in d-c circuits.

Switch Developments

The preceding discussion concerns conventional switch design. An important electric function, such as aircraft switching, demands equipment designed specifically for the purpose. A great deal of effort has been expended in the last two years in the attempt to interest aircraft-accessory manufacturers in the design and production of hermetically sealed switch gear. Obviously, a switch with contacts sealed in an enclosure with hydrogen or some other suitable gas under pressure would not be deleteriously affected by altitude variation, humidity, moisture, ice, dust, foreign matter, contact oxidation, and ionization. A small hermetically sealed switch manufactured by the Western Electric Company for use in submarine cables was tested with encouraging results. This switch, measuring one quarter of an inch in diameter and two inches in length, had magnetic leaf-type contacts enclosed in a hydrogen atmosphere. The switch was actuated by an external magnet and satisfactorily interrupted more than one ampere at 115-volts direct current in a circuit having an L to R ratio of 0.020. This same switch is adaptable to electromagnetic operation as a relay. At the present time higher-capacity 15-ampere sealed switches and relays with double-throw contact arrangements are being developed by several companies.

Relays

In general the remarks concerning switches apply as well to relays. A line of relays originally designed for three-phase 208-volt alternating current recently has been given 115-volt d-c ratings. They are available in three sizes up to 5-kw continuous duty and 20-kw rupturing capacity. For d-c use the ratings are based on series connection of the three poles, thus constituting a single-pole relay having a six-break mechanism.

Another relay originally designed for 24-volt direct current has been adapted to 115-volt d-c service by the addition of an 0.05-ounce Alnico magnet for each pair of contacts. Tests indicated that this relay would interrupt safely ten amperes at 30,000 feet and six amperes at 50,000 feet.

It is interesting to note that an industrial-type relay rated 100 amperes at 115 volts direct current weighed 25 pounds, while a comparable aircraft relay designed for the same voltage weighed only 1.75 pounds. Assertions that higher voltage will result in extremely heavy switch gear probably are founded on the consideration of such commercial equipment. It should be noted that the aircraft units were designed to much more severe requirements for an ambient-temperature range of +158 to −85 degrees Fahrenheit, and for vibration and acceleration loads in excess of ten grams. In fact, this 115-volt relay weighs less than a 24-volt relay having a comparable power rating. The weight of a high-current 24-volt contact mechanism is inherently heavier than that for the lower-current 115-volt power equivalent. Specifically, the weight of current carrying components is substantially greater than that of arc suppression mechanisms.

Circuit-Protection Devices

Circuit breakers incorporating electromagnetic arc extinction have proved satisfactory for 115-volt aircraft circuit protection. Design investigations are being conducted to adapt these circuit breakers to overload protection and circuit-switching service. The General Electric Company has a series of 208-volt a-c 115-volt d-c fuses which may be preferred to circuit breakers.

Lighting

Filament Characteristics

In the design of aircraft 24-volt lamps for low-wattage sizes, the filament has been drawn to minimum diameter and in some cases has been etched to reduce further the cross-section area. When it is suggested that lamps be designed for 115-volt service, it is argued that filaments are already too fragile. In many instances these low-wattage lamps give insufficient light and would be better replaced with brighter lamps. To get this higher output the filament need only be increased in length, the diameter being the same. In increasing the length it is assumed that the filament support will be of a sturdy vibration-resistant character. The filament-diameter worry exists only with the low-wattage low-lumen output lamps. The filament of a 50-watt 115-volt lamp could be the same diameter as the widely used 15 candle power 24-volt aircraft lamp. The increased efficiency of the electric generating system plus the reduced power loss in high-voltage distribution systems, since much of the cable already will be of minimum gauge, permits the use of higher-wattage lamps. The problem with 115-volt landing lamps is with the filament support rather than with the filament diameter. Several 115-volt lamps with different-type filament supports have been tested under simulated aircraft-vibration conditions. Certain lamps which have especially designed vibration-resistant filament supports operated for at least 250 hours when vibrated over a range of 100 to 3,600 cycles per minute with a total excursion of 0.031 inch. Therefore, it is concluded that satisfactory lamps are available in 20-, 40-, and 50-watt sizes.

Lamp Life Affected by Mounting

Where lamp life is important the lamp-assembly mounting should be designed carefully. An actual lamp installation was mounted on a platform and vibrated with a 0.031-inch total excursion. The filament movement was measured to be from 0.062 to 0.25, depending on the resonant characteristics of the mounting. This is mentioned because lamp failure is frequently the result of faulty installation rather than lamp design. Shock mounting of lamp assemblies may be desirable to increase the life of certain essential lamps such as landing lights.

A-C Lamps

Filament resonance, sometimes encountered with a-c lighting and especially with 400-cycle power, does not exist with direct current. In order that phase balance may be maintained during lamp on and off conditions it is necessary that high-wattage lamps for alternating current have special three-phase filament structures. For smaller lamps it is general practice to distribute lamp loads among the three phases with resultant wiring and phase-balance complication.

Present Supply Problems Temporary

The aircraft electrical designer is having difficulty in obtaining a wide variety of adequate 115-volt lamps. This is probably due to the high production demands on lamp manufacturers because of war necessity.

Radio

It is frequently stated that alternating current is ideal for radio power, while direct current, because of voltage-conversion difficulties, is not. This is a fallacy, because fundamentally radio equipment requires direct current which is normally obtained from alternating current by rectification and filtering. The aircraft radio designer seldom chooses tubes for desired d-c potentials but instead resorts to dynamotors, inverters, and transformers. This procedure is neither desirable nor necessary. At present 24-volt direct current is being used successfully as the only operating potential in some aircraft radio receivers and in at least one transmitter, except for the power stage. Equipment so designed has proved the equal of previous designs in all respects and superior as regards to voltage breakdown of capacitors and insulation. A d-c potential of 115 volts can be used with greater facility and even better results. Beam-power amplifiers represent a step in the direction of low-voltage transmitting tubes.

Motors

General Considerations

On large airplanes having a gross weight of over 100,000 pounds, 150 or more motors may be installed. On one well-known airplane at least 125 motors are used for armament alone. Although motors represent as little as 20 per cent of the airplane electrical equipment, they may constitute as much as 75 per cent of the entire electric load.

Motor weight is a function of the performance required. In general the weight of d-c motors for high-starting and peak-torque service will be less than for alternating current. For example, a peak output of eight horsepower will require a two- or three-horsepower d-c motor or about a four-horsepower a-c motor. On the eight-engine airplane previously referred to, about 70 per cent of the motors were estimated to be of the high-torque intermittent-duty type.

Motor Efficiency

Efficiency of intermittent-duty equipment is not important, since power loss due to inefficiency of such equipment is negligible. The weight of intermittent-duty equipment can be reduced by designing for lower efficiency, and such weight saving usually will more than justify such design. Only where the peak horsepower requirements of a motor approach the peak generation output of the aircraft electric system is efficiency of intermittent-duty motors a critical factor.

The efficiency of a 115-volt d-c motor will be higher than that of a comparable 24-volt motor due to lower brush losses. For a given power output a 115-volt d-c motor will be lighter than an equivalent low-voltage motor by virtue of smaller commutator and brushes.

Brushes

A great deal has been said recently concerning brush wear. Many conflicting theories have been expounded for the erratic performance of brushes at high altitude. It is not within the scope of this discussion to review or conjecture on the suppositions now prevalent. Excessive brush wear at high altitudes usually has been evident where current densities have approached 200 amperes per square inch.

As a result of current military need for improved 24-volt brush life, research and development have progressed to the point where 1,000 hours' service has been assured for motors and generators from sea level to 40,000 feet. The same techniques will be applied to 115-volt d-c rotating equipment with even longer brush life. In the near future brush maintenance on d-c motors may be almost negligible in view of the development of new brush materials.

Explosion-Resistant Motor Requirements

Identical explosion-resistant requirements exist for both a-c and d-c, high or low voltage motors. The assumption that brushless motors are explosion proof is unjustified since they are equally susceptible to:

1. Faulty workmanship.
2. Insulation breakdown.
3. Stalled rotor overheat.

Any of these faults may result in ignition of explosive fuel mixtures.

Power Generation

Altitude Effects

Military demands have increased the altitude ceiling of airplanes to 40,000 feet or more. This does not mean that such high-altitude flight will prevail after the war. Airplanes may fly as high as 25,000 feet in order to avoid storm conditions, but it is probable that commercial transport and cargo planes seldom will be flown above 20,000 feet. Direct current is generally conceded as being satisfactory for electric power up to 25,000 feet, but it is claimed that alternating current is the only answer for very high altitudes. Lengthy technical papers have been published in which higher-voltage d-c system considerations were dismissed with a few perfunctory remarks to the effect that higher-voltage d-c power is not suitable for high-altitude service. Experience and test results indicate that direct current is not only adequate, but may be the best type of very high-altitude aircraft power. Satisfactory performance of d-c inverters, radio dynamotors operating at 1,000 volts or more, and electric fuel pumps on airplanes being flown at extremely high altitudes substantiate this statement. The a-c systems now under consideration employ a d-c generator for alternator excitation. This practice seems inconsistent if d-c generation is not considered entirely reliable at high altitudes. Objection to the use of direct current at high altitudes has come from the improper use of equipment of doubtful low-altitude design at 30,000 to 40,000 feet. The failure of marginally designed equipment, such as generators having brush current densities of over 200 amperes per square inch, does not constitute valid reason for objection to the

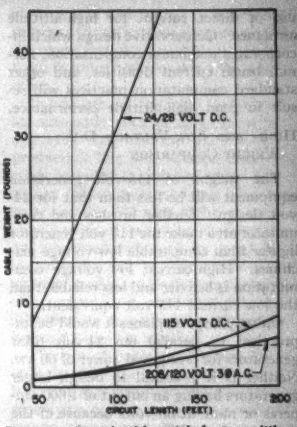

Figure 3. Aircraft cable weight for transmitting three horsepower

Figure 4. Three-wire feeder

use of direct current for high-altitude airplanes. Conservative design which incorporates maximum compensation, normal brush current densities, and other standard commutation practices will result in good high-altitude performance.

High- and Low-Voltage D-C Weight Comparison

The weight of 115-volt generation equipment will be less than that for 24-volt design. Smaller brushes and commutator area make the 115-volt generator lighter than comparable low-voltage machines. High-current low-voltage commutation is heavier and less reliable than the low-current 115-volt equivalent.

On very large airplanes it would be impractical to parallel ten 24-volt 6-kw generators for a required power of 60 kw. Neither is it practical to design larger generators having an output of 1,000 amperes or more at 30 volts because of the commutation difficulties and unwarranted commutator weight. Present 115-volt generators are at least 15 per cent lighter than equivalent 24-volt units. Appreciable weight savings are obtained for the 115-volt d-c voltage-regulation equipment. On the same eight-engine airplane it was estimated that the high-voltage generation system was lighter than the low-voltage generation system by approximately 150 pounds.

A-C and D-C Weight Comparison

There should be little difference in weight between comparable a-c and d-c generators when the necessary alternator field excitation is included. Comparison of constant-speed alternators with variable-speed d-c generators is confusing and wrong. The important weight difference between a-c and d-c machines comes from generator drive requirements. A variable-speed d-c generator is very much lighter than the combination of an alternator and its associated constant-speed drive mechanism. The speed of airplane propulsion engines is varied from approximately 1,000 to 3,000 revolutions per minute. To maintain constant frequency within practical limits it is necessary to interpose an automatic constant-speed transmission to drive the alternator from a main engine. The weight of a variable-speed d-c generator is somewhat more than that of a constant-speed generator, but this weight difference is small compared with the weight of a constant-speed drive mechanism required for constant-frequency alternating current. This constant-speed transmission device is proving to be a serious design problem. It is expected that the weight of these constant-speed drives can be reduced approximately to two pounds per horsepower for the 60-kw alternator. In addition to an estimated 150-pound weight penalty the constant-speed drive creates unknown hazards and complication.

The difficulty with a-c design does not end with securing relatively constant frequency. There is the additional problem of providing means for paralleling the alternators. The relative position of paralleled 400-cycle alternator rotors must be the same with only a very small angular displacement permissible. Equipment to accomplish such synchronization is usually complex.

A method of avoiding parallel operation of alternators is to divide the airplane loads between two independent alternators with automatic means for transferring the loads from an alternator, which may fail, to the remaining one. The divided load system will require more elaborate distribution wiring and bus installations, more extensive load protective measures, and complicated transfer equipment. The load transfer system to be practical must be automatic and sufficiently rapid, so that there is no appreciable interruption of service. There should be no danger of stalling motors, of de-energizing relays, nor of interrupting solenoid-operated equipment. A load transfer system is usually troublesome, and its design is technically difficult. The reliability of such a system is questionable and cannot be compared with the inherent safety and simplicity of parallel-operated d-c generators.

For alternating current, a divided load system on large aircraft will require two alternators driven at a constant speed, each of which must have sufficient capacity to carry the entire load. The size and weight of the alternator and constant-speed-drive combination does not permit direct mounting on a main engine. A remote accessory drive shaft and gear box would be required, and it is to be remembered that space aft of the engine is at a premium. A proposed remote drive for each 30-kva alternator was estimated at 50 pounds, a weight penalty which a-c systems can ill afford. If it is assumed that a large airplane will require 60 kva, the generation system will have 120 kva available in two alternators. For the same requirements six main engine-driven 15-kw d-c generators can be used with much greater reliability. The six d-c generators having 90-kw output will be considerably lighter than the 120-kva alternator installation.

Auxiliary Engine Power

Auxiliary engine-driven aircraft alternators have been operated successfully in parallel, and this system constitutes a standby until the proposed systems are proved satisfactory. The reason for present consideration of other a-c power systems is the weight inefficiency of constant-speed auxiliary electric drives which will be explained.

Auxiliary power may be the answer to many electrical design problems, but the efficient use of such power cannot be obtained where constant speed operation of the auxiliary engine is required. This is because the average electric load for long flights may be less than 30 per cent of the peak demand. The fuel consumption may be reduced only 36 per cent for a 70 per cent reduction of load. Another cause of high auxiliary engine fuel consumption is the fact that, to compensate for the loss of power at altitude and to supply customary short-time overload capacity, the auxiliary engine size must be increased considerably over the nominal requirements. For a required 50-kw peak load at 20,000 feet, a 175-horsepower auxiliary engine is needed. Of this 175 horsepower an average of only 15 kw will be used in flight, yet 64 per cent of the full-load gasoline consumption will be required. An estimate of fuel required by two 50-kw auxiliary engines operated at constant speed throughout a 25-hour flight was 600 pounds more than for main engine-driven generators.

Fuel consumption of auxiliary engines can be reduced materially by governing engine speed in conformity with load requirements. This may be accomplished by providing a load-sensitive speed governor for the auxiliary engine, driving a variable-speed d-c generator. A two-to-one speed regulation of the auxiliary from peak load to average load is required to show favorable weight comparison with present main engine-driven designs. Load governing of the auxiliary between wider limits would result in additional weight savings. It is obvious that the advantages of variable-speed load governed auxiliary power-plant design are practical only with the use of direct current.

Where auxiliary power plants are installed for engine starting and for on-the-water operation, it is desirable that they also be used in flight. Because of vibration complications, service troubles, and crowded accessory compartments, it is desirable to remove the generators from the engine. By centralizing the power supply a material saving can be made in wiring and bus weight.

Battery Power

In the electric-system design there may be some need for limited amounts of stored energy which can be supplied by storage batteries. Depending on the capacity required, it may prove lighter to install a small auxiliary power plant in place of the storage battery. In either case the stored energy can be conveniently a part of a d-c system. The battery constitutes an extremely inefficient source of electric power, and its use will be avoided wherever possible.

Conclusion

For large aircraft, regardless of altitude service, 115-volt direct current is more practical than either 24-volt direct current or 208/120-volt 400-cycle three-phase alternating current. The 115-volt system is considerably lighter than either the 24-volt d-c or the a-c system.

Application of Electronics to Aircraft Flight Control

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PROBABLY no other control problem offers so many opportunities for the advantageous application of electronics as the design of equipment for automatic flight control. The type *C*-1 Autopilot used in the Army's heavy bombardment aircraft is a typical example of equipment in which the use of electronic devices has produced a flexible well-co-ordinated control system from what was formerly an unwieldy electromechanical machine.

Inherent Design Problems

To appreciate fully the problems in the design of an automatic pilot it is first necessary to understand the fundamental principles of flight control.

The control of an airplane can be resolved about three perpendicular axes, as illustrated in Figure 1. When the position of the airplane is such that its roll and pitch axes are horizontal and its turn axis is vertical, it will fly "straight and level"; but, whenever the airplane is made to rotate about one or more of these three axes by movement of its ailerons, elevators, or rudder, its flight path is changed. The ailerons, elevators, and rudder therefore are called the *control surfaces* of the airplane. It is important to remember that the position of these control surfaces does *not* determine the airplane's position, but rather the rate of the airplane's rotation about its corresponding axes. This characteristic of airplane flight control makes it necessary for the pilot to perform double operations in executing simple maneuvers.

As an example, consider the operation of the ailerons in making a left turn. First the airplane is made to roll to the left by displacing the ailerons—the left aileron upward, the right aileron downward. As the airplane reaches the desired angle of bank, the ailerons again are streamlined to stop further rotation, and the airplane remains in the bank until the desired turn has been made. The ailerons are then displaced in the opposite direction for the time required to return the airplane to level flight. Rudder and elevator controls are operated in a similar manner, except that the elevator and, to a lesser degree, the rudder are not completely streamlined during the maneuver.

Another complication in aircraft flight control arises from the fact that, in most turning maneuvers, the ailerons, rudder, and elevator all must be operated simultaneously to produce a proper turn. Too much rudder will cause a skid; too much aileron, a slip; and too little up-elevator will permit the plane to lose altitude in the turn. Therefore, any automatic pilot must accurately proportion the movement of each control to fit a complex pattern and, at the same time, co-ordinate the movement of all controls to maintain them in proper relationship with one another.

In addition, it is highly desirable for an automatic pilot to be so universally adaptable that identical units from the production line will operate effectively when installed in different types of airplanes. Since different types of aircraft have widely different flight characteristics, and since these same characteristics are influenced materially by speed, loading, altitude, and weather conditions, an automatic pilot, to be universally adaptable, must have provisions for easily adjusting its operating characteristics to match those of the airplane.

The use of vacuum-tube circuits not only simplifies the solution of these problems but also makes possible a degree of sensitivity and accuracy not obtainable by any other means. These features are of basic importance in an automatic pilot designed for high-altitude precision bombing.

Description of Autopilot Equipment

The primary function of an automatic pilot is to fly the airplane straight and level. It must operate the controls quickly and smoothly in response to any deviations from an established attitude and heading.

In the *C*-1 Autopilot the vertical flight

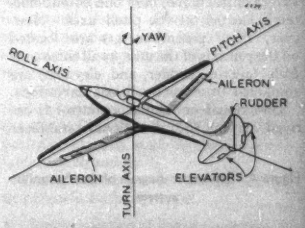

Figure 1. Flight-control axes of an airplane

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Although a few problems exist with the use of either high-voltage system, those for direct current are not difficult, while a satisfactory solution for the many a-c problems is questionable.

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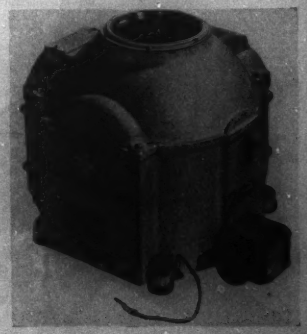


Figure 2. Vertical-flight gyroscope

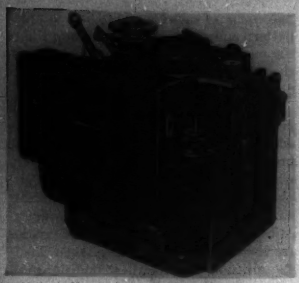


Figure 3. Directional stabilizer

gyroscope is employed as a reference for roll-axis and pitch-axis deviations (see Figure 2). Its outer case is mounted firmly to the structure of the airplane, but its rotor is universally mounted within the case so that the gyroscope's automatic erection system can maintain the roter axis vertical, regardless of the position of the airplane. Any tilting of the gyroscope case with respect to the rotor is measured electrically by four potentiometers within the unit. These potentiometers have their windings fastened to the case and their sliders held in position by the gyro rotor. The resulting electrical signals activate the system to restore the aircraft to level flight. Since pitch-axis deviations are corrected by elevator control alone, only one potentiometer is located on the pitch axes. However, three potentiometers are located on the roll axis of the unit, as all three controls (aileron, rudder, and elevator) are employed to correct roll-axis deviations.

Directional or turn-axis control is derived from the directional stabilizer (Figure 3), which contains a horizontal gyroscope. The rotor of the horizontal gyroscope tends to remain fixed in space, unaffected by turning movements of the airplane. Here again, potentiometers with their windings fastened to the outer case and their sliders held in position by the gyro-rotor assembly are used to measure electrically any course deviation of the airplane. Two potentiometers are used, one for rudder control, the other for aileron control.

Thus, in the two gyro-controlled units a total of six potentiometers are employed as the sensing elements of the system. The individual units are identified in Figure 4 by the numbers 1 and 10, and the potentiometers by the numbers 5, 6, 11, 12, 13, and 14. A seventh potentiometer (number 2 in the illustration) is an auxiliary part of the Autopilot, used to energize a direction indicator (7) on the pilot's instrument panel.

Figure 5. One of the three servo units

No less important in the operation of the Autopilot are the motorized servo units which do the actual work of moving the control surfaces (see Figure 5). Three such units are required, one each for ailerons, rudder, and elevator. (In Figure 4 these units are located at 15, 18, and 19.) Each servo unit contains an electric motor which drives a cable drum through a differential gear train. Two solenoid-operated clutches control the direction of cable-drum rotation; one clutch turns the drum in one direction, the other in the opposite direction. An automatic brake mechanism effectively holds the cable drum stationary when neither of the two clutch solenoids is energized. Cables wound on the servo-cable drum are attached to the main control cables which move the control surfaces.

Each servo unit also contains a balancing potentiometer with its winding fastened to the servo-unit frame and its slider attached to the cable drum. The purpose of these balancing potentiometers will be revealed later in the explanations of the controlling bridge circuits.

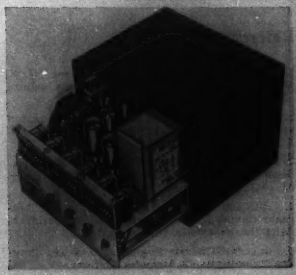
The seven-tube amplifier (Figure 6) is the electronic brain of the Autopilot. It contains three distinct channels, one for each of the three flight-control axes (item 16 of Figure 4). Each channel contains two tubes—a 7*F*7 double-amplifier stage, a 7*N*7 discriminator stage, and two relays which operate the clutch solenoids of the related servo unit. For the moment, each channel of the amplifier may be thought of as a motor controller which analyzes the amount and direction of control-surface movement called for by the sensing potentiometers in the bridge circuit and which then operates the corresponding servo unit accordingly.

Manual control and adjustment of the system are provided by the Autopilot control panel (Figure 7). This unit centralizes at the pilot's fingertips the various switches and control knobs by which he engages the system, aligns the Autopilot with a selected attitude and heading, adjusts the sensitivity of the Autopilot, regulates the amount of control surface applied to correct a given deviation, and co-ordinates interrelated control functions. A "turn control" is included by which the human pilot can execute turns and evasive tactics without disengaging the Autopilot.

Power for the d-c components of the system is supplied by the airplane's batteries. A rotary inverter provides the

Figure 4. Schematic diagram of the Autopilot system

Figure 6. Autopilot amplifier



19-volt, 105-cycle a-c power required. The entire Autopilot equipment, with all seven motors, 14 solenoids, and seven-tube amplifiers energized and operating, draws only 7.6 amperes from the 26-volt d-c batteries. Normal voltage and frequency variations have relatively little effect on the performance of this Autopilot system.

The Bridge Circuits

If the gyroscopes are thought of as the *eyes* of the Autopilot, the servo units as the *muscles*, and the amplifier as the *brain*, then the bridge circuits might be likened to the nervous system by which all these components are interconnected.

There are three distinct bridge circuits of the resistance type in the system—one each for aileron, rudder, and elevator control. Each bridge circuit provides the input to a specific amplifier channel which, in turn, operates one of the servo units.

Figure 8 is a schematic diagram of the aileron bridge circuit, which has been simplified for the purpose of explanation. The aileron-control potentiometer, shown at the top of the diagram, is located in the vertical-flight gyroscope and is sensitive to roll-axis deviations of the airplane. The balancing potentiometer at the bottom of the diagram is actuated by the cable drum on the aileron servo unit. Both potentiometers are energized by a common transformer in the amplifier.

If we apply Kirchhoff's law to this circuit,

$$e_1 - e_2 = E \qquad (1)$$

As long as e_1 and e_2 are equal, E is zero and no signal is applied to the amplifier, and the servo unit remains stationary; but, when the control potentiometer is displaced, e_1 and e_2 are no longer equal and a signal E is impressed on the amplifier. Depending on the phase characteristic of E, the amplifier then causes the servo unit to drive the balancing potentiometer in the proper direction to make e_2 equal to e_1 and thereby reduce E to zero. In effect, the potentiometers, amplifier, and servo unit comprise a self-balancing bridge circuit in which the balancing potentiometer produces a corresponding movement of the cable drum to drive the control surfaces of the airplane. This is the fundamental operating principle of the *C*-1 Autopilot.

Actually, of course, the circuit is complicated somewhat by the necessary inclusion of additional control potentiometers, as shown in the diagram of the aileron bridge circuit (Figure 9). The principle of operation, however, is the same; and the same type of equation applies:

$$E = e_1 \frac{r_1}{R_1} + e_2 \frac{r_2}{R_2} + (e_3 - e_4 - e_5) \qquad (2)$$

In this equation, E is the voltage output of the entire bridge circuit, and e_5 is the voltage applied by the balancing potentiometer.

When E is zero, the circuit is balanced and the system is at rest; but, whenever any potentiometer in the system is moved, the voltage (E) is effective on the amplifier and causes the servo unit to drive in the proper direction to adjust e_5 to such a value that E again will be zero.

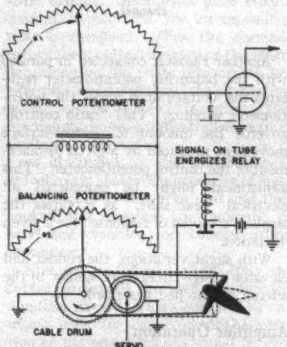


Figure 8. Simplified bridge circuit

In normal flight, e_1 and e_3 are zero, because the potentiometer wipers are at their center taps, as indicated by the dotted lines on the diagram. The other values are such that E is zero and the circuit is in balance. When the airplane is blown off course, the banking potentiometer on the directional gyroscope is displaced. This produces a signal, e_3, which causes operation of the servo unit and a corresponding increase in the value of e_4 to rebalance the circuit. Movement of the ailerons immediately causes a bank and consequently a reduction of e_3 as the vertical-flight gyroscope is tilted. This reduction of e_3 offsets the effect of e_4 and results in reversal of the servo unit to streamline the ailerons when the degree of bank becomes proportional to the directional deviation.

Figure 7. Autopilot control panel

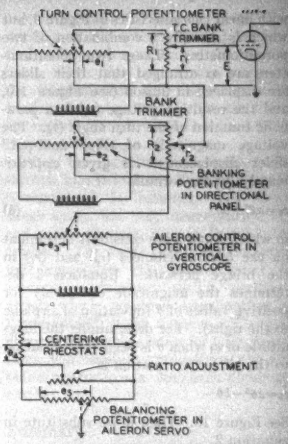


Figure 9. Complete bridge circuit

Meanwhile the airplane is turning back toward its original heading, reducing the value of e_3. Since e_3 is now less than the change of e_4, the circuit is again unbalanced, and the servo unit applies opposite aileron to reduce the degree of bank. As the airplane levels off, the value of e_3 increases toward its original level-flight value. Because both e_3 and e_4 now are approaching their normal values, the servo unit again reverses to restore e_4 to its normal value. Thus, the ailerons reach their trim position in level flight as the original heading of the airplane is restored.

Note that the turn-control trimmer and the bank trimmer are provided to regulate the effect of the turn-control and banking potentiometers by applying the fractional factors r_1/R_1 and r_2/R_2.

Among the advantages of using potentiometers in a-c bridges are:

1. Simple isolation of voltage sources.
2. Controllable amplification of small signals.
3. Linearity of control characteristics.
4. Nondistortion of wave forms.
5. Full 180-degree phase change at balance point.

A linear relationship exists between the deviation in attitude of the airplane, as measured by the potentiometers on the gyroscope and the displacement of the control surfaces. The voltage output of a bridge potentiometer can be considered as practically proportional to the displacement of the sliders, because of the high impedance of the amplifier input circuit when compared to that of the bridge circuit. The one exception to this linearity is the banking potentiometer on the directional gyroscope, which is represented by a single potentiometer

with linear characteristics in Figure 9, but which is actually a combination of two potentiometers. These two potentiometers are so arranged that their sliders are displaced in unison (see Figure 10), and the resulting voltage (e_2) is a parabolic function of the turn angle (θ). The voltage magnitude of this "dual-pot" slider displacement is given approximately by the formula

$$e_2 = a\theta^2 + b\theta \qquad (3)$$

in which a and b are constants dependent on the fixed resistances (r_3) and (r_4) in the bridge network. Equation 3 determines the magnitude of e_2 only for positive values of θ (deviation of airplane to the right). For determining the magnitude of e_2 when θ is negative (deviation to the left), the equation is

$$e_2 = a\theta^2 - b\theta$$

See Figure 15. Then if we substitute in equation 2,

$$E = e_1 \frac{r_1}{R_1} + (a\theta^2 + b\theta)\frac{r_2}{R_2} + (e_3 - e_4 - e_5) \qquad (4)$$

Employment of the resistance bridge with electronic motor control permits the substitution of simple and easily accessible electrical adjustments in place of more difficult mechanical adjustments. As an analogy, imagine how much easier it would be to adjust the carburetor, tappets, and distributor of your automobile if it could be done by turning knobs as you do in selecting a station on your radio. In the electronic Autopilot this ease of adjustment is attained simply by connecting rheostats (located on the control panel) to the bridge circuit as shown in Figure 9. The two centering rheostats are mounted on a common shaft connected in series with the balancing potentiometer, as shown. When the resistance of one is increased, the resistance of the other is decreased. This arrangement permits the pilot to shift the electrical center of the balancing potentiometer in either direction to align the circuit with the mechanical trim position of the control surfaces. These centering potentiometers thus can be likened to "electrical trim tabs."

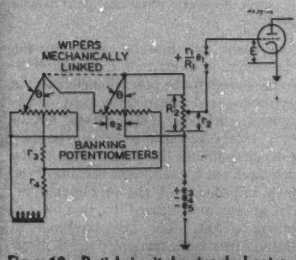


Figure 10. Partial circuit showing dual potentiometer arrangement

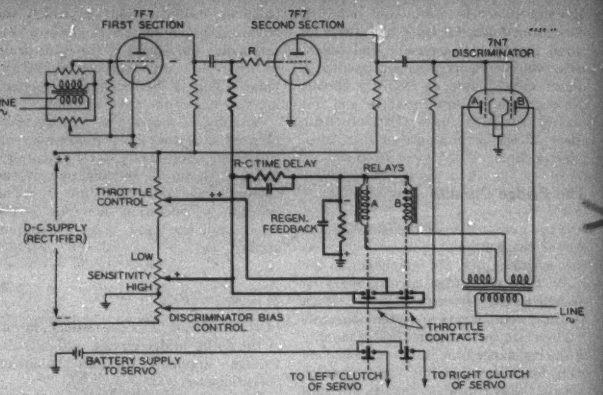


Figure 11. Schematic diagram of one amplifier channel

Another rheostat connected in parallel with the balancing potentiometer regulates the voltage drop across the potentiometer winding. This "ratio control" governs the amount of control-surface movement produced by a given displacement of the control potentiometer. This adjustment might be considered an electrical "gear shift," as it varies the airplane's "speed of response" for a given deviation.

With slight variations, the rudder and elevator bridge circuits are similar to the aileron circuit just described.

Amplifier Operation

So far, the amplifier has been described merely as a phase-sensitive motor controller which responds to any unbalance of the bridge circuits by closing the proper relay, thereby producing the required servo-unit operation. How the amplifier works and how it introduces special control characteristics are revealed by the schematic diagram of one of its three channels (see Figure 11).

Note that only two tubes are used in each channel, one *7F7* and one *7N7*. The first section of the *7F7* tube is used strictly as an amplifier, with no d-c bias applied to the grid. The second section, however, is employed in a unique way as a control tube, with three separate controlling voltages applied to its grid.

Attention is called, first, to the resistance R which is connected in series with the grid of the second section. It is apparent that any voltage impressed on the left-hand end of this resistor is proportioned between the resistor and the internal grid resistance. When the applied voltage is negative, no current will flow between cathode and grid, as the grid resistance becomes practically infinite. Therefore, the entire applied voltage is impressed on the grid. However, when the applied voltage is positive, current flows between cathode and grid, because the grid resistance becomes very low in comparison with the resistance of R, and hence only a small fraction of the applied voltage actually is impressed on the grid. Thus, negative signal voltages applied to the resistor produce sharp plate-current fluctuations, whereas positive voltages do not cause any appreciable change in plate current (see Figure 12). In effect, this resistor lowers the saturation point of the tube's characteristic curve and produces a very flat curve beyond that point.

It is apparent from the resulting characteristic curve (Figure 12) that the *sensitivity* of the tube can be controlled by applying a variable positive bias. Thus, when the tube is biased at point A (high sensitivity) a small signal will produce

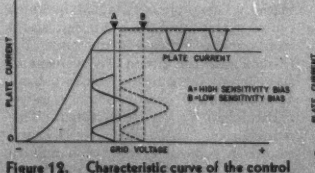


Figure 12. Characteristic curve of the control tube, illustrating the effect of changing sensitivity bias

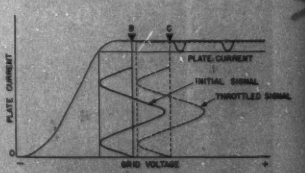


Figure 13. Characteristic curve of the control tube, illustrating the effect of throttling bias

plate-current variations. But when the tube is biased at point *B* (low sensitivity), the same signal is ineffective, and a larger signal is required to produce plate-current fluctuations. This sensitivity bias is knob-controlled by a potentiometer (Figure 11) located on the Autopilot control panel.

The sensitivity bias is applied continuously, but, under certain conditions of operation, two additional bias voltages are applied to this same tube section. One is a negative feed-back voltage which has the effect of increasing the tube's sensitivity whenever either half of the 7*N*7 discriminator tube is passing current. The other is a throttle voltage, of higher positive value than the sensitivity bias, which is applied to the tube whenever the throttle contact on either of the two relays is closed. The effect of this throttle voltage is to increase the bias on the grid to point *C* (Figure 13), thus blocking any signals which are not sufficiently large to overcome this increased bias.

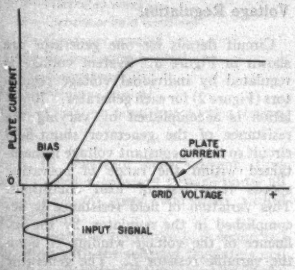


Figure 14. Characteristic curve of the discriminator tube

(Referring to Figure 13, note that a signal which produces plate-current fluctuations when the tube is biased at *B* is ineffective when the bias is changed to *C*.) A resistance–capacitance time-delay circuit serves to maintain the throttle bias on the tube for a short time after the relay contacts reopen.

The purpose of the feed-back circuit is to insure that the weakest signal capable of overriding the bias of the control tube will be amplified sufficiently to drive the discriminator tube, and thus produce positive nonchattering operation of the relay.

The discriminator tube, which employs alternating voltage on the plates, is biased negatively to the cutoff point. This bias is sufficiently large to prevent any current flow through either half of the tube when no signal is applied to the grid (see Figure 14).

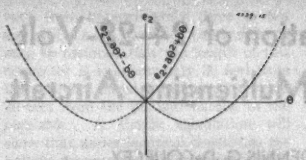


Figure 15. Output voltage of dual banking potentiometers versus directional deviation of airplane

It is apparent from the diagram (Figure 11) that since the two plates of the discriminator tube are connected to opposite ends of similar transformer windings, the voltage of one plate is always 180 degrees out of phase with the voltage of the other plate. When the signal applied to the interconnected grids is positive, the electrons will flow from the cathode to whichever plate is positive at the same instant. Since each plate circuit contains a relay coil, the corresponding relay is energized. Thus the discriminator tube operates one relay or the other, depending on the phase relationship between the input signal and the alternating plate voltage supply. In effect, this discriminator is a grid-controlled rectifier similar to a thyratron.

As illustrated by the diagram, individual relays control the operation of separate clutches in the servo unit and thus control the direction and amount of servo-unit rotation or control-surface movement.

Now, let us follow a signal from the bridge circuit all the way through the amplifier circuit. This signal will be one which calls for counterclockwise rotation of the servo unit, as would be produced by energizing the left-hand clutch solenoid. That is, the signal is in phase with the voltage at plate *A* of the discriminator tube. The signal is first amplified and reversed in phase by the first section of the 7*F*7; then it is applied to the grid of the second section where it produces plate-current pulsations during the negative half of the cycle. Since the signal phase again is reversed in the second section, these plate-current pulsations apply a positive half-wave signal to the discriminator tube which is in phase with plate *A* of that tube. The resulting current flow energizes relay *A*, which in turn energizes the left-hand clutch solenoid of the servo unit.

At first the signal on the control-stage grid of the 7*F*7 is sufficiently large to override the additional positive bias introduced by the closure of the throttle contacts on the relay. However, as the servo unit drives the balancing potentiometer toward the balance point, the signal gradually is reduced until its negative peaks no longer exceed the throttle bias. When this occurs, the signal to the discriminator tube is interrupted, causing the relay to drop out for about one-eighth second while the time-delay capacitor discharges.

When the capacitor is discharged, the throttle bias is lost and the signal to the discriminator is restored. The relay closes again, but only momentarily, because the throttle bias is thereby reapplied. The result is that, as the servo unit approaches the balance point, it operates intermittently with a "pecking" action which prevents overshooting or "overcontrol" of the airplane. The rate of correction, which is fast for large deviations, will diminish gradually as the airplane approaches a stabilized-flight attitude.

Summary

In automatic flight control, as in other control problems, the limit of flight accuracy through mechanical and electrical controlling methods seems to have been reached. Only by the application of electronic-control principles has it been possible to set new standards and to achieve full flexibility of control with completely automatic operation of all control functions. Furthermore, these advantages have been obtained with actual reductions in the total weight of equipment.

Since the use of an automatic pilot for precision bombing imposes complex and rigid requirements which are not encountered in commercial aeronautics, it can be confidently stated that the continued development of electronic controls will produce a small lightweight, foolproof automatic pilot for peacetime use. Because of the precision bombardment Autopilot, the control industry is certainly richer in knowledge and experience, and will be better able to cope with the new problems of peacetime industry.

Although the connection now seems obscure, some of the applications in the development of the type *C*-1 Autopilot were taken from a cabin-temperature-control system. In a similar way, the principles employed in both systems have been found useful in the automatic regulation of engine power. And so, in a seemingly endless chain, each new development brings to light the solution of another problem. Who knows what application these same developments will find in enlarging the prosperity, health, and happiness of a peaceful world?

Paralleling and Regulation of 24–28-Volt D-C Generators in Multiengine Aircraft

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Synopsis: This paper presents the findings of a rather extensive program of testing electric systems in aircraft. Only the system which is presently being used in most United States Army Air Forces multiengine aircraft and a proposed system, which has been designed as the result of the tests, are described. All intermediate steps are not discussed since it is felt that the effects of these steps have been reflected in the proposed system. The proposed system differs from the present system primarily in that it employs separate networks for power feed and distribution instead of a common bus. Several desirable features of such a system are pointed out. Equipment is discussed in a general manner since the aircraft designer is concerned with the design of equipment only insofar as it affects the operation of the system. However, quite often the aircraft designer is in a position to make suggestions for improvement of the equipment.

MOST large United States Army Air Forces aircraft of the present day employ the type of electric system that is outlined by the Army Air Forces specification 32300, "Installation of Electrical Equipment, General Specification for." This is a 24–28-volt d-c single-wire grounded negative system in which the nominal rating of the batteries is 24 volts and the engine-driven generators deliver power at 28 volts. All power is fed into and taken from a common bus which interconnects all wiring of the airplane as shown in Figure 1.

Four main-engine-driven generators and one or more batteries supply power to the airplane. An auxiliary power plant, gasoline-engine driven, is available for ground operation, take-off, and landing. A bus exists across the airplane from number 1 to number 4 nacelles and from the nose of the airplane to the tail. Each generator feeds into the bus at its respective nacelle through a reverse-current relay. The batteries feed into the bus through a relay which is operated by the pilot. External power may be supplied to the airplane while on the ground through an external power plug. It can be seen from this that normally there are five sources of power feeding into the bus: the four generators and the batteries. It is evident that electrical resistance must exist between each and every feeder point. With current flowing the voltage drop, or differential voltage, between inboard and outboard nacelles may be as much as one-quarter volt. To overcome this differential, the outboard generators must generate a higher voltage than the inboards if equal load distribution is to be expected.

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Generator Relay

The generator is connected to the bus by a relay (see Figure 2) which closes only when the generator is delivering voltage higher than a predetermined value (approximately 26 volts). A small "pilot" relay *V* which determines the "cut-in" voltage operates a set of contacts *T* in the main winding. The generator switch which is controlled by the pilot completes the circuit. In addition, the relay opens in the event that generator voltage drops below bus voltage and causes reverse current to flow through the generator. Permanent magnets are used to polarize the pilot relay so that current passing through coil *R* in the normal direction strengthens the field but reverse current induces magnetomotive force in opposition. As the induced magnetomotive force approaches the strength of the permanent field the attraction on the relay armature is nullified and the contacts open. It is this function that gives the relay its common designation as a reverse-current relay.

A new relay has recently been developed to replace the reverse-current relay. It is referred to as a differential-voltage relay and gets its name from its operating characteristic. Provided the generator is delivering voltage higher than the bus voltage by a minimum value (between 0.25 and 0.50 volt) the relay will close and put the generator in service. In this case, the "pilot" relay operates on the differential in voltage between the generator and bus. There is a series current coil, similar to that in the reverse-current relay, which performs the same functions. These are:

1. To keep the pilot contacts closed after the main relay closes, at which time the differential between generated and bus voltage no longer exists.
2. To open the relay when a reverse current of sufficient magnitude flows into the generator.

Voltage Regulation

Circuit details for one generator are shown in Figure 3. System voltage is regulated by individual voltage regulators (Figure 2) for each generator. Regulation is accomplished by varying the resistance of the generator shunt-field circuit so that a constant voltage is maintained within the range of operating speeds regardless of load conditions. This variation of field resistance is accomplished in the regulator, by the influence of the voltage winding *N* upon the variable resistor *L*. The generator field current is taken through the resistor; variation in resistance causes varia-

Figure 1. Schematic wiring diagram, typical four-engine airplane

1—Engine-driven generator
2—Reverse-current relay
3—Voltage regulator
9—Auxiliary power plant
L—Load center

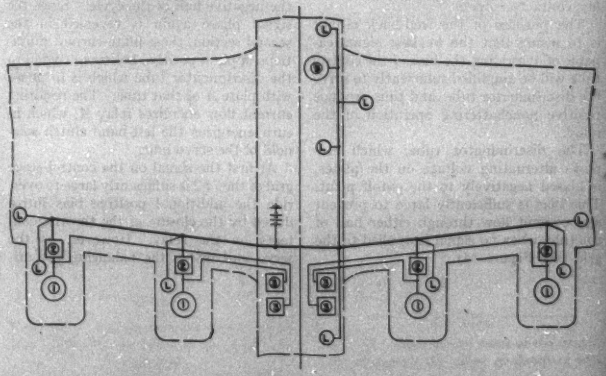


Figure 2. Schematic wiring diagrams, typical equipment

A—Generator field terminal
B—Generator positive terminal
D—Equalizing-coil terminal
E—Generator negative terminal
G—Ground (negative) terminal
K—Equalizing-coil terminal
L—Variable resistor (field)
M—Equalizing winding
N—Voltage winding
O—Variable resistor (adjusting)
P—Fixed resistor (current-limiting)
Q—Rectifier
R—Series current coil
S—Main relay winding
T—Pilot relay contacts
U—Main relay contacts
V—Pilot relay winding
W—Generator field windings
X—Generator armature
BAT—Bus connecting terminal
SW—Switch terminal
NEG—Negative terminal
GEN—Generator positive connecting terminal

tion in generator field current, thus maintaining a constant voltage under all conditions of speed and load within rated limits.

The variable resistance *O* is connected in series with the solenoid regulating coil so that a greater or lesser portion of the line voltage is imposed on the regulating coil, thus increasing or lowering the regulating voltage. Normally, this is the only adjustment made on the regulator.

The regulator is connected to the individual system at the generator side of the reverse-current relay, and is centrally located in the fuselage of the airplane for accessibility in flight. This results in another voltage differential in the system, in addition to the voltage drops in the busses because the connection between the reverse-current relay and the regulator is a different length for each generator. In considering the functions of this connection it is necessary to analyze the currents which it must carry. They are:

1. The current necessary to energize the regulator.
2. Field current for the generator.
3. Operating current for the voltmeter.
4. Operating current for main winding of the reverse-current relay.

It follows that a connector intended to energize the regulator is performing three additional functions. All of these currents are reasonably constant except the generator field current which may vary from approximately three to ten amperes. As a basis for comparison it may be assumed that the length of this connector is approximately 30 feet from the outboard nacelle to the regulator and 20 feet from the inboard nacelle to the regulator. A simple calculation will show that under identical conditions the voltage drop across this connector would be 50 per cent higher for the outboard nacelle than for the inboard. The effect of this condition upon the generator, as shown in Figure 4, is that the generated voltage exceeds the regulator setting by a value equal to the drop across the line. In some cases this value may be as high as one volt. This analysis shows that under all conditions the outboard generators will be delivering a different voltage than the inboards, if all regulators are adjusted to the same value. Hence, a natural tendency for poor load division is introduced.

Load Division

Voltage regulators are provided with an equalizing circuit, which tends to make all generators deliver equal current. The equalizing circuit provides for equal distribution through the influence of winding *M* on winding *N* and the resultant effect on resistor *L*, as shown in Figure 2, by lowering the voltage of the generators which are tending to deliver high current and conversely raising the voltage of those generators which are delivering comparatively low current. In this respect, if one generator is out of service and the equalizing circuit is left intact, it will endeavor to lower the voltage of the others. At the same time the regulator will tend to raise the voltage of the "off" generator so that it will take more load. Since the one generator is inoperative, as far as the system is concerned, its voltage is zero. It is impossible to lower the voltage of the other machines to such a value. However, the equalizing circuit will exert its full energy to accomplish this. The result is a drop in voltage of the generators in service. The magnitude of this voltage drop is dependent upon the number of generators in the system, the generators out of the service, and the total load on the system. At any time a generator is out of service the respective reverse-current relay is open whether the pilot's control switch indicates "on" or "off." For instance, if the switch is "on" but the generator speed drops to a point where it can not carry the load its reverse-current relay will open and remain open until the speed rises again. Thus, it becomes desirable to devise some method whereby the equalizing circuit will be opened automatically. The simplest method for accomplishing this is to add auxiliary contacts to the reverse-current relay. This would require practically no change in the airplane wiring since the equalizing connection from the generator to the regulator usually passes close to the relay.

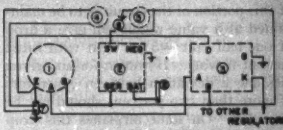


Figure 3. Schematic wiring diagram, one generator circuit

1—Generator
2—Reverse-current relay
3—Voltage regulator
4—Ammeter
5—Voltmeter
6—Generator switch (control)
7—Ammeter shunt
8—Positive bus

Another solution to the problem employs a double-pole single-throw toggle switch rather than a single-pole single-throw as the generator switch. The extra pole is used to open the equalizing circuit at the same time the generator switch is opened. This accomplishes the desired results provided the generator is intentionally put out of service or the operator knows the generator is inoperative, and opens the switch. The objections to this solution are that it is not automatic and additional resistance is introduced by the additional wiring which is required to extend the circuit to the point at which the switch is located.

Energy for the equalizing circuit is obtained from a voltage drop across a portion of the generator circuit, which is specifically the connection between airplane structure (ground) and the *E* (negative) terminal of the generator, as shown in Figure 3. In accordance with Air Corps Specification 32,300 the resistance

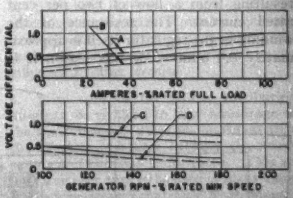


Figure 4. Differential in generated voltage and regulator setting due to resistance of connections between the generator and voltage regulator for a typical four-engine aircraft

Solid curves—Generator on outboard engine
Dashed curves—Generator on inboard engine
A—Generator operating at rated minimum speed
B—Generator operating at rated maximum speed
C—Generator delivering rated full-load current
D—Generator operating at no load

of this portion of the circuit is to be maintained at a value which will give a drop of one-half volt ±5 per cent with rated current flowing. However, for any given airplane a deviation between generators of more than two per cent should not be exceeded. On some airplanes this drop is accomplished through the use of a given length of copper conductor, the resistance of which may vary widely with temperature. Consequently, the voltage drop may vary with ambient temperature and load conditions. In some airplanes this condition is accentuated by the ground circuit for the inboard generators being located in the wheel well. The conductors which comprise the circuit are exposed to outside air temperatures, which may differ by as much as 200 degrees Fahrenheit from the ambient temperature in the outboard nacelles. The ammeter shunt is usually located in this circuit and with the necessary connectors contributes to the required resistance. A loose connection anywhere in the circuit may cause erratic results as to the voltage drop under given conditions, since contact resistance varies widely when passing current. In this type of installation, all such connections must be controlled. Furthermore, it is important that the ground connection be made to basic structure. In some cases this connection is made to anodized parts. The resistance of an anodized connection is as unpredictable as a loose connection. The equalizing circuit has a low resistance and operates on low voltages. Since the total voltage is one-half volt across the ground circuit at full load and the equalizing circuit is to operate not on this entire value but on differences existing between generators, if a two per cent tolerance is to be maintained in load distribution, the equalizing circuit must be capable of operating on voltage differentials down to 0.01 volt, the drop resulting from a flow of two per cent rated current. The resistance of the winding in the regulator itself is approximately 0.4 ohm. For this reason it is important that the connection between the generator ground circuit and equalizer circuit of the regulator have a low resistance. Assuming that the lead resistance is no more than 0.1 ohm, the total resistance of the circuit for one generator is 0.5 ohm. With 0.01 volt across this value of resistance the current flow would be in the order of 20 milliamperes.

To minimize the effect of resistance changes of the generator ground circuit due to temperature it is desirable to use a material having a lower thermal coefficient of resistivity and a higher resistivity than copper. Such a material would result in a more constant resistance under all temperature conditions and a probable reduction in weight. Manganin, which is widely used in instrument shunts, is the most logical choice for this purpose. Manganin is at present a critical material. However, even during normal conditions its cost would probably prohibit its use. Nichrome was found to be a suitable substitute. Based on the use of 200-ampere generators, a resistor necessary to provide a one-half volt drop weighs only 10 ounces compared to approximately 3.5 pounds of wire used for the same resistance. Another advantage of having such a unit rather than a length of wire is that it can be calibrated before installation to a close tolerance. When a resistor of this type is used it is advisable to make the equalizer-circuit connection at the resistor rather than at the generator. This makes the connection across only a calibrated unit and eliminates the effect of the necessary connections in the circuit. The importance of this can not be stressed too highly since successful parallel operation depends primarily on the equality of the ground-circuit resistance.

From the standpoint of weight saving and wiring simplification, it is desirable to incorporate the ammeter shunt with the resistance unit. It is a simple matter to tap off a portion of the resistor which will give the same voltage drop as the ammeter shunt now being used. This value is usually 50 millivolts at 300 amperes. The addition of such a tap increases the weight of the resistor unit by a negligible amount, whereas the ammeter shunt weighs approximately 12 ounces. This eliminates an extra part as well as several connections.

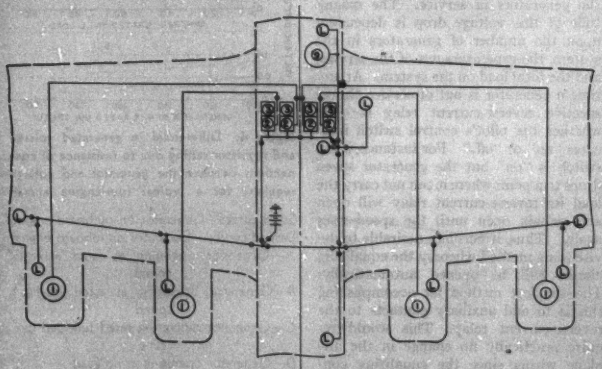
Study of the foregoing shows that there are four major points to consider which affect load distribution between generators. They are:

1. The location of the reverse-current relay with respect to the system.
2. The length and size of connection between the reverse-current relay and the regulator.
3. The resistance value and equality of the generator ground circuits.
4. The total resistance and equality of the regulator equalizing circuits.

The power in such a system is drawn from the bus at various points; that is, at each nacelle and several points within the body of the airplane. There is no central power distribution poiut.

Figure 5. Schematic wiring diagram, proposed system

1—Engine-driven generator
2—Reverse-current relay
3—Voltage regulator
9—Auxiliary power plant
L—Load center
⊖—Location for suitable circuit protector



Proposed System

A desirable aircraft electric system would utilize all of the previously described equipment and eliminate the undesirable characteristics of the present system. As the result of tests conducted on the component parts and the system as a whole in the laboratory and on airplanes, a revised system,* shown in Figure 5, was proposed. The proposed system consists primarily of two networks, one a feeder network and the other a distribution network. All power is fed into and taken from a single point which is common to the two. The output of each generator is fed directly into the body of the airplane to a central point, where its reverse-current relay and voltage regulator are located, mounted adjacent on a panel. There is an individual panel for each generator. The output sides of the relays are connected by bus to the central power point. This constitutes the feeder network. A radial network distributes power to various load centers in the airplane.

Analysis of this system shows that regulator connectors of excessive and unequal lengths are eliminated. Line re-

* Navy Department Bureau of Aeronautics outlines a similar system for large aircraft in specification *SR-8*. Therefore, the proposed system is not entirely new except in its application to large Army Air Forces aircraft.

The Gyrosyn Compass

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IN all military and commercial aircraft, the gyroscope is depended on for attitude and direction references. The vertical spinning gyroscope provides attitude indication in the form of the artificial horizon. At present, other attitude representations based on the vertical gyroscope are available. The use of the vertical gyroscope has been accepted for 15 years or more, and will be further improved for indication of roll and pitch but probably never superseded. The indication of azimuth, or heading of the airplane, which is actually the attitude around the vertical axis called direction, up to the present has had no standard means of presentation. In the past, magnetic compasses have been used for this purpose. These instruments for aircraft use are imperfect, and it has been found necessary to supplement this type of indication with a secondary reference in the form of a directional gyroscope. With the addition of the directional gyroscope, the inherent defects of the compass are greatly minimized. These defects are well known and can be stated as

1. Lack of stability.
2. Northerly turning error.

The directional gyroscope is essentially a gyroscope with the spin axis horizontal and mounted in gimbals with freedom about the vertical such that it tends to stay fixed in space around this vertical axis. A card fixed or geared to the vertical-axis gimbal will show changes in heading and for appreciable periods of time will provide a reference for maintaining a straight course. It is, however, subject to slow wander, and therefore must be corrected once in a while by manual resetting. This is done holding flight on a straight and level course. Then the conventional magnetic compass gives fairly reliable information and the directional gyroscope can be set to agree with its average reading. It is obvious that this system of periodically resetting the directional gyroscope to compensate for its random drift is a serious handicap to instrument flying. Also, in military aircraft, the usefulness of the magnetic compass in the cockpit is diminished because of the disturbances on the magnetic field due to the proximity of electrical components and armor plate.

Statement of Problem

The purpose of this paper is to describe, in a general manner, the development and characteristics of a system which largely eliminates these serious shortcomings. The first approach to a problem of this kind is to establish the basic requirements of a satisfactory direction-indicating system. The requirements are as follows:

1. The indication shall be stable in all conditions of air turbulence.
2. No manual resetting or attention on the part of the pilot shall be required.
3. The readings must be free from deviation and deviation changes.
4. Several repeaters of the indication must be provided for, each giving a stable or deadbeat indication.
5. The equipment must be simple, both mechanically and electrically, and all parts requiring periodic service must be easily accessible.
6. The accuracy must be commensurate with the limitations of the earth's magnetic field.
7. Turn errors must be negligible.
8. The entire system shall have minimum weight and volume.

In attacking this problem, several points stand out. It becomes apparent that it is necessary to operate from the earth's magnetic field at some part of the aircraft remote from magnetic disturbances and to transmit the indication to various points convenient to the flight personnel. The location for the magnetic sensitive unit should be in a part of the airplane where deviation and deviation changes are zero, or a minimum. Therefore, it must be away from guns, turrets, cargo, motors, and so forth. Such a location may, for example, be the very tip of a wing, the top of the vertical fin, or some part of the stabilizer. To enable mounting in such confined spaces, the unit itself should have the smallest possible physical dimensions. It also should be simple and rugged, to withstand the vibration and buffeting that is often severe in remote parts of the airplane. In addition, since such locations prob-

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sistance between relays is eliminated. All equalizing circuits have equal resistance. In such a system the disadvantages of the present system are overcome. In addition, a reduction in the weight of the electric system seems possible.

In any electrical service circuit protection against fault damage is usually employed. Circuit protection is particularly desirable in military aircraft because of possible damage from enemy gunfire. Parallel wiring has been advanced as a possible method of protection against failure of electric equipment due to damage of wiring from gunfire. Combat experience has indicated that such damage is not frequent. However, if the added precaution is desired parallel wiring can be applied to any system. Parallel wiring is a modification of any given system and should not be considered an additional system.

Locations for suitable circuit protectors are shown on Figure 5. The term "suitable protector" is used because no one type of protector is capable of performing the desired functions in every location. Various sizes and types will be required. Comparison of Figures 1 and 5 will show the difficulty in attempting comparable protection with the present system.

A comparison of the two systems shows that the desirable features of the proposed system are as follows:

1. There is a central distribution point from which all power is taken.
2. All power is fed into and regulated at this point.
3. Better load distribution between the generators is obtained because all generators are electrically symmetrical about the load center and do not have inherent circuit inequalities which the regulator must overcome. The only function the equalizing circuit of the voltage regulator is required to perform is that of compensating for irregularities in the voltage regulation.
4. Relays and regulators are accessible in flight for adjustment and replacement, if necessary.
5. Since each individual circuit on the airplane carries primarily its own load current, it is possible to provide adequate circuit protection for a given circuit without undue influence on other circuits.
6. Wire sizes of the power distribution lines can be reduced to take advantage of the central supply point to the extent that the effective resistance between the power supply and the load is decreased. This allows a smaller wire to be used in many cases where wire sizes are controlled by resistance. In many cases it is possible to rate the wire thermally allowing a reduction in wire weight. A comparison of the two systems as used on a typical four-engine aircraft shows that a weight reduction of approximately 38 pounds is effected by replacing connectors with smaller wire sizes wherever possible.

Observations on test airplanes employing the proposed system have shown that voltage regulation and power distribution are improved. Also, maintenance time required for the electric system has been decreased.

ably are somewhat inaccessible, the device must be particularly durable to eliminate frequent servicing of that part. All other parts subject to periodic servicing must be in the cockpit or other easily accessible location.

Gyrosyn Compass

The Gyrosyn compass provides one method of meeting the indicated requirements. This system consists essentially in automatically and continuously correcting the directional gyroscope for its random drift by indications derived from a direction-sensitive device located in a magnetically undisturbed region of the airplane. The need for manually resetting the directional gyroscope is eliminated, and it thereby serves also as a space-stabilized compass. The direction-sensitive device is termed a flux valve. It may be located in practically any part of the airplane because it is small. In this system, the directional gyroscope is synchronized by the flux valve to magnetic meridian. This explains why the name "Gyrosyn" was selected.

Vertical Gyroscope Analogy

It is interesting to note that this treatment of the directional gyroscope for direction indication is an exact analogy to the conventional use of the vertical gyroscope in which oscillations of short-period pendulums are integrated to establish accurate attitude indications without recourse to manual resetting. Why the directional gyroscope remained a "free-gyro" device for so many years after the vertical gyroscope was made to be controlled deserves explanation. First, simple devices such as the flux valve were unobtainable at the time the first gyro vertical was constrained to seek the vertical of its own accord, and also old-style magnetic compasses were fairly adequate until flying conditions became too exacting. Actually, controlled directional gyroscopes have been in use for a number of years, mainly in Europe. These, however, do not provide the simplicity of a short-period pendulum, are expensive to build, and while providing stable indications, fail to meet other requirements set forth above.

Description

A representative installation of the Gyrosyn compass is shown in Figure 1. It is noted that an alternate position of a flux valve is indicated. The system comprises two main units shown in Figure 2, Gyrosyn indicator (with amplifier), flux valve with connecting cable and optional repeater unit; Figure 3 shows the flux valve (close-up). The primary indication in this system is the directional gyroscope, and it is shown in the cockpit for use by the pilot as a flight indicator. This is the normal application. There are cases, however, in which the primary indicator may be allotted to some other member of the crew, such as the navigator. The sensitive pickup device embodying the flux-valve elements is shown in Figure 4. It is essentially a permeable-core device having an exciting winding and three phases spaced 120 degrees with signal pickup coils on each. A voltage is generated in the respective coils, depending on the relative position in the earth's field. By virtue of the fact that the output voltage changes sinusoidally with the position of each phase in the earth's field, it is possible to indicate the direction of the earth's magnetic field relative to the flux-valve element at a distant point. This is done by connecting the coils to respective phases of a self-synchronous unit located at primary indication location. Without going deeply into the theory of operation, it suffices to say that the induced voltage of the rotatable secondary winding of the self-synchronous unit has a magnitude and polarity determined by its angular displacement relative to the angular displacement between flux-valve element and the earth's magnetic field. By properly positioning the secondary winding, or rotor of the self-synchronous unit, angularly, a null signal may be obtained. This is the normal self-synchronous position. The rotor of the self-synchronous unit is linked mechanically to the vertical ring of the directional gyroscope. The electrical and mechanical schematic diagram of this system is shown in Figure 5. Shown also on this diagram is a precessing device which applies torque around the horizontal axis normal to the spin axis of the gyroscope. The precessional torque is controlled in magnitude and direction by the polarity and strength of the signal from the rotor of the self-synchronous unit, after amplification and rectification. The torque applied about the horizontal axis of the gyroscope simply produces rotation around its vertical axis, thereby driving the self-synchronous-unit rotor to a position where the signal becomes zero. In other words, the gyroscope is constrained to the position that maintains null self-synchronous-unit output. This means that the spin axis of the gyroscope will remain oriented in a fixed position relative to the earth's magnetic field, or magnetic meridian. The directional gyroscope, therefore, seeks the magnetic meridian in a manner very similar to the way in which a vertical gyroscope seeks the vertical. The only conditions under which the output of the self-synchronous unit is not null occurs when the gyroscope in its normal manner slowly drifts away from its correct azimuth position, or when the system is "turned on," preparatory to making a flight, that is, the period of

Figure 1. Airplane with Gyrosyn compass

Gyrosyn-compass system
C-1—Turn-indicator adaptation
Total weight with one flux valve and two repeaters 11½ pounds estimated
A—Flux valve and mounting bracket—weight 1 pound actual
B—Gyrosyn-compass indicator—weight 8 pounds estimated
C—Gyrosyn-compass repeater—weight 1¼ pounds actual
1—Gyrosyn-compass indicator
2—Repeater
3—Flux valve
4—3 phase, 400 cycles, 115 volts, 27 volts direct current
5—Indicating pointer
6—Course setter
7—Cover

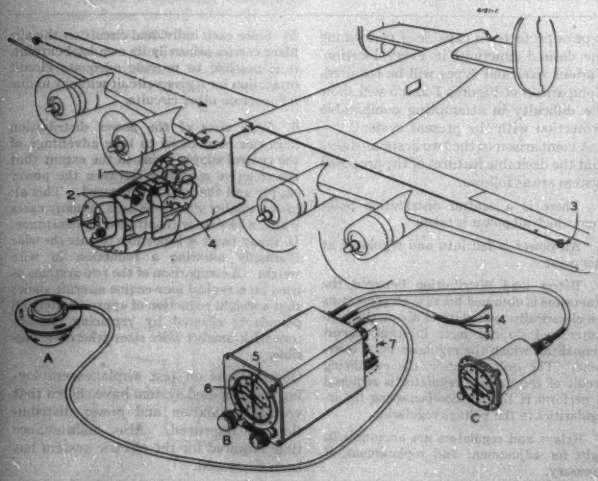

Figure 2. Gyrosyn-compass indicator (with amplifier), flux valve with connecting cable, and optional repeater unit

initial synchronizing. Heading changes are made without precessing the gyroscope and without losing synchronization. This is due to the fact that the magnetic meridian with respect to the flux valve and the directional gyroscope and self-synchronous unit with respect to the aircraft move through exactly equal angles, and therefore the null is not disturbed. The acceleration experienced in turn will temporarily disturb the null, but this will not produce a serious error, as described later. It is shown in Figure 5 that the flux valve in itself is a pendulum with two degrees of freedom. It is suspended on a universal joint in a manner normally to keep the plane of the flux valve horizontal. This must be done so that the indication obtained from this element represents the direction of only the horizontal component of the earth's magnetic field. Thus, a change in attitude of the airplane in roll or pitch cannot tilt the flux valve. It will remain in the horizontal plane. Certain disturbances, however, momentarily may swing it out of the horizontal. Such disturbances will make the signal fluctuate and give momentary erroneous data. In rough air, the signal may almost continually fluctuate. This brings us to the important function of the directional gyroscope as a primary indicator. It serves effectively to integrate all short-period disturbances and oscillations. The maximum precession rate as called for by the flux valve through the self-synchronous unit is limited. The period of pendulum, on the other hand, is so short that a single oscillation of the pendulum cannot be detected by observation of the gyroscope. The result in the Gyrosyn is that this system provides deadbeat accurate indications that are unchanged by any weather conditions.

Turning Error

So far, it has been shown that most of the requirements stated in the beginning can be met by a simple addition to the directional gyroscope, and by two extra elements, the flux valve and the amplifier. A deadbeat remote-indicating magnetic compass is obtained. Another of the requirements stated is the reduction of the northerly turning error. This error does exist in the Gyrosyn compass as in any magnetic-compass system that directly or indirectly is controlled by gravity. If the craft is turning, the resulting acceleration acts on the pendulum to displace it from a horizontal position. This results in an erroneous signal, the amount and direction of which depends on the instantaneous heading of the aircraft during the turn. The gyroscope, therefore, commences to move away from the magnetic meridian, but it does not do so rapidly. As a matter of fact, for a normal

Figure 3. Flux valve (close-up)

turn the duration is not sufficiently long to cause the gyroscope to be in error more than a few degrees, usually not more than five degrees. If the turn continues indefinitely, or, in other words, the airplane continues to circle, the error signal reverses on itself and does not cause accumulation of gyro errors. Rather, the gyro indication will slowly move back and forth about its correct position. It should be noted that definite limits are placed on the gyro precession rate. The precession characteristics against angle of error is nonlinear. This being the case, sustained oscillation of the pendulum resulting from air turbulence or poor manual flying, may cause desensitization of the coupling between flux valve and gyroscope. To overcome the oscillation, a small amount of damping is introduced on the flux-valve pendulum. It is accomplished by enclosing the element in a sealed chamber and filling with damping fluid. The damping coefficient may vary through wide limits without impairing the accuracy of the Gyrosyn compass, and therefore wide variations in temperature encountered do not, by changing the damping-fluid viscosity, affect the system operation.

Alternate Turn-Error Corrections

In applications where the gyroscope is used as an automatic-pilot reference for rudder control, another means of limiting turn errors is usually available. Turns with an automatic pilot are initiated by a co-ordinated control of some sort. This control can be used to suspend the flux-valve signal for the duration of the turn. The gyroscope therefore becomes a free directional gyroscope with no constraint and will accumulate for the duration of the turn only a very negligible error because of its random wandering. At the resumption of straight and level flight, flux-valve control is automatically applied, and the gyroscope is again under the gentle influence of the flux valve. The same effect may be accomplished in a Gyrosyn system, independent of the automatic pilot by having the flux-valve signal interrupted by a rate-of-turn relay, such as a rate gyroscope. For most practical cases, however, the small temporary error induced with flux-valve control functioning during the turn is of no importance.

Accuracy

In stating the accuracy of the Gyrosyn compass as in any other type of remote-indicating magnetic compass, the conditions first must be fully defined. With variation of plus or minus 40 cycles in supply frequency and a corresponding change in voltage, both alternating and direct, and field strength change from 0.04 to 0.40 oersted, and the maximum error of definition is plus or minus $1^1/_2$

Figure 4. Flux-valve element

degrees from the magnetic meridian to the gyro indicator. Higher accuracy could be obtained but is hardly justified in view of the limitations of the earth's magnetic field. However, when electric generators and power supplies are improved to be more constant in voltage, frequency, wave form, and so forth, these performance figures will automatically be further improved.

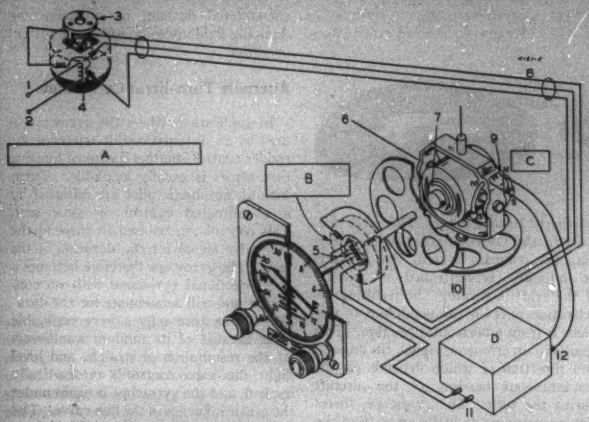

Figure 5. Schematic diagram of flux valve, self-synchronous units, gyroscope, amplifier, and precessor

A—Pendulously mounted flux valve
B—Signal transformer
C—Gyroscope
D—Amplifier
1—400 cycles
2—Excitation
3—Mounted to wing structure
4—Signal pickup coils
5—Rotor coupled to gyroscope
6—Horizontal axis
7—Gyro rotation
8—Connecting cable
9—Precessing coil
10—Vertical axis
11—Input: 800 cycles
12—Output: reversing-polarity direct current

Compensation

Primarily the size of the flux valve lends itself to mounting in very small recesses anywhere in the skin of the airplane. Therefore, in a number of types of airplanes, a location sufficiently remote from magnetic disturbances is available such that compensation is not required. This has been the experience with several standard types of airplanes, in which experimental Gyrosyn compass installations had been made. However, there may be some applications in which local deviations are obtained in every possible location of the flux valve. In these cases compensation must be resorted to. Conventional permanent-magnet compensators are available and add only a fraction of an inch to the over-all dimensions of the flux valve. Because the flux valve naturally will be located in a fairly inaccessible part of the craft, compensation by manual adjustment at that point may be impractical. It is possible to make available means for overcoming this difficulty. This is a method of applying compensation to the magnetic field by remote adjustment. A compensator consists of electromagnets distributed properly around the flux valve. The current in these coils is controlled by rheostats located conveniently in the cockpit or cabin. The compass may be swung either on the ground or in the air and compensated in a straightforward manner by adjustment of the potentiometers. This system is shown schematically in Figure 6. In cases where electric circuits are in close proximity to the valve, these circuits may be linked with the compensation circuit in such a way that full correction is obtained either "on" or "off."

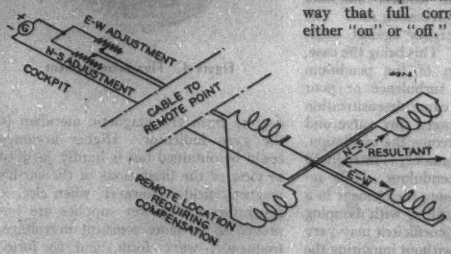

Figure 6. Compensation schematic diagram

Polar Navigation

The Gyrosyn compass obtains reliable operation in horizontal-field strengths greater than 0.04 oersted. However, in regions near magnetic poles, this field strength fades to the vanishing point. In the same region, directional indications obtained from the earth's field are unreliable and difficult to interpret, because of rapid changes in variation. These rapid changes make it necessary to obtain impossibly accurate position data to determine the correct local variations. This loss in magnetic directional information is not particularly serious to the Gyrosyn compass, since the flux-valve control may be turned off, leaving the directional gyroscope as a free gyroscope. Therefore, headings can be substantially maintained for hours or more of flight until reliable magnetic information again can be obtained through the earth's magnetic field. The flux-valve control of the gyroscope will be turned on and navigation resumed in a normal manner. In summing up the characteristics of the Gyrosyn compass in operation over widely varying field strengths, it is indicated that operation without adjustment is obtainable down to the region where magnetic indications become totally unreliable. Then, the precessing control of the gyroscope is suspended and a free navigational directional gyroscope remains.

Conclusions

The directional gyroscope has served many years usefully as an aircraft instrument. It has well-known shortcomings, but it fills a tremendously important place in the field of navigation. Its days of functioning as a free gyroscope subject to random wandering, however, are numbered. From now on, the directional gyroscope is going to be continuously controlled, and the direction-indicating instrument will require no more attention and manipulation from the pilot than the attitude-indication instrument, namely, the artificial horizon, has for a number of years. It is believed that the system described herein contributes a fair share in bringing about this change. No development of this sort can be said to be successful until it is received with approval by the armed services, airplane builders, and commercial operators, and most important, by the pilots themselves. The requirements for remote-indicating compasses that have been stated are an interpretation of the composite demand from all of these groups. It is believed, therefore, that in adhering to this set of requirements a satisfactory directional indicator is produced.

Electric Automatic Pilots for Aircraft

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AUTOMATIC pilots have been in use for many years in both commercial and military aircraft and are well suited to normal airplane control. Their greatest usefulness is in maintaining heading and attitude over long periods of time, with consequent reduction in strain on the human pilot.

Recently, however, with the development of bombardment tactics, the need for precise control has become more important. The functions of an automatic pilot for these applications are such that the maintenance of course, attitude, altitude, and trim are at times of paramount importance. It is necessary that the airplane, through the medium of the automatic pilot, respond quickly to turns as called for by the bombardier. Furthermore, it is desirable that the performance deteriorate as little as possible when the airplane is subjected to the disturbing action of turbulent air. This paper discusses the problems associated with such control and describes some of the features of a recent design.

Attitude Control

The minimum requirement of any automatic pilot is the angular stabilization of the airplane about three mutually perpendicular axes passing through the airplane's center of gravity and angularly fixed with respect to the surface of the earth. Motions about these axes are described as roll, pitch, and yaw. Rolling is rotation about the fore and aft, or longitudinal axis; pitching is rotation about the transverse, or lateral axis; yawing is rotation about the vertical, or directional axis. These motions are illustrated in Figure 1. Under certain conditions, the problem of simultaneous control about an airplane's three rotational axes can be reduced to three independent control systems. Each control system is then similar, and discussion will in general be confined to one axis.

Control of an airplane, manual or automatic, is accomplished through the deflection, or angular rotation of the airplane's control surfaces about the surface hinge line. Rotation of a control surface is, in effect, a change in angle of attack of the surface and gives rise to an aerodynamic force normal to the surface. The control surface forces, in turn, create control moments about axes through the center of gravity of the airplane. The angular acceleration caused by a control moment continues until the resulting damping and stability moments are equal to the control moment. The angular rotation tends to cease when the control moment is equal to the static stability moment. A given control moment therefore is opposed by an inertia moment, a damping moment, and a static stability or spring moment. The magnitude of these moments varies considerably between axes and for different flight conditions. If control moment is maintained until appreciable changes in flight path occur other moments are

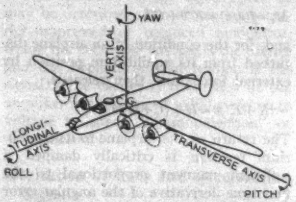

Figure 1. Schematic drawing of airplane showing its three translational axes and the three angular degrees of freedom

generated which, however, may be disregarded here.

For short-period motion, the application of pitching-control moment and the resulting rotation about the transverse axis may be expressed as

$$M_c = I\ddot{\theta} + C\dot{\theta} + K\theta \qquad (1)$$

where

M_c = applied control moment about the transverse axis
I = moment of inertia of the airplane about the transverse axis
C = damping coefficient, or damping moment per unit rate of pitch
K = stability coefficient, or restoring moment per unit angle of pitch
θ = angular displacement in pitch

The foregoing equation is subject to several restrictions. It is approximately correct for small angles of pitch and describes the angular motion only for a short time after control moment is applied. The static longitudinal stability, actually a function of change in angle of attack, is assumed to depend on the angle of pitch. It is further assumed that the coefficients C and K are constant for a particular condition of flight.

For automatic stabilization, the control moment becomes a restoring moment, M_r, and is made a function of the angular error, θ, between the airplane attitude and a gyroscopic reference axis. The restoring moment applied by the automatic pilot then acts to reduce the error to zero in a manner determined by the combined characteristics of airplane and automatic pilot. Assume that the airplane is coerced from its equilibrium position and then released. It is then acted upon by the restoring and the static stability moments such that

$$M_r = f(\theta)$$

and

$$-f(\theta) - K\theta = I\ddot{\theta} + C\dot{\theta} \qquad (2)$$

If the restoring moment is proportional to the error alone, as in many automatic controls,

$$M_r = f(\theta) = K'\theta$$

and

$$-(K + K')\theta = I\ddot{\theta} + C\dot{\theta} \qquad (3)$$

The static restoring moment, $K'\theta$, supplied by the automatic pilot, acts to in-

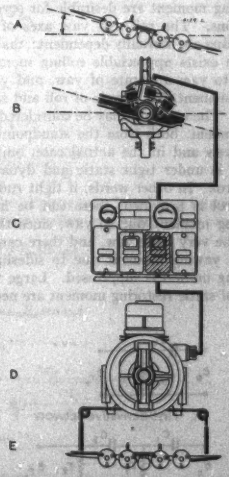

Figure 2. Pictorial representation of the A-5 automatic pilot controlling the airplane in roll

A—Roll angle
Airplane deviates in roll
B—Vertical gyroscope—horizontal gimbal ring and roll pick-off measure roll angle
C—Amplifier rack—roll signal is amplified and derivatives are taken
D—Servo unit deflects ailerons
E—Airplane returns to level flight

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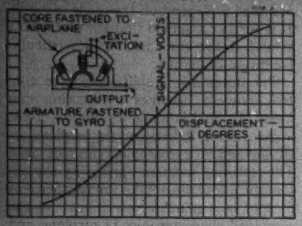


Figure 3. Schematic diagram of signal pick-off and its voltage-angle characteristic

crease the static longitudinal stability, $K\theta$. Where "tight" control is necessary, the stability furnished by the automatic pilot must be several times larger than the inherent stability of the airplane. Control which is proportional to the displacement error alone is known as error control.

When K' is sufficiently large, and

$$C<2\sqrt{(K+K')I}$$

the angular motion is a damped oscillation and undamped natural frequency is

$$f_n=\frac{1}{2\pi}\sqrt{\frac{(K+K')}{I}}$$

Reasonably large values of static restoring moment are desirable for several reasons. The roll and yaw axes of an airplane are mutually dependent; that is, there exists appreciable rolling moment due to yaw and rate of yaw, and yawing moment due to rate of roll and sideslip. The two axes may be considered independent, both from the standpoint of analysis and in the actual case, only if each is under tight static and dynamic control. In other words, if tight rudder control is provided, there can be little rolling moment due to yaw, since there can be very little yaw, and there can be little yawing moment due to sideslip if rolling motion is suppressed. Large values of static restoring moment are necessary too, when any sustained disturbance is encountered, such as an engine failure in multiengine ships; a sudden sustained change in trim, as when a large bomb is released; or a long-period air disturbance.

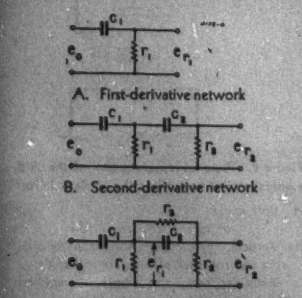


Figure 4. Derivative-taking networks

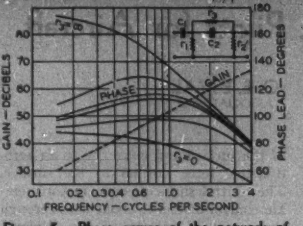


Figure 5. Phase curves of the network of Figure 4C for different values of r_2

The broken curves are measured phase and gain for the rate channel of the amplifier

Additional damping moment is obtained by making the restoring moment proportional to the time derivative of the angular error as well as the error itself, so that

$$M_r=f(\theta,\dot{\theta})=K'\theta+C'\dot{\theta}$$

and, for the condition of an airplane disturbed from its equilibrium position by external forces and then released,

$$-(K+K')\theta=I\ddot{\theta}+(C+C')\dot{\theta}$$

The return of the airplane to its equilibrium position is critically damped if sufficient moment proportional to the first time derivative of the angular error is available, or

$$(C+C')=2\sqrt{(K+K')I}$$

This type of damping is often called error-rate damping.

The return of the airplane to level attitude after it has been subjected to a disturbance must be at least critically damped because of the nature of the disturbances encountered in rough air. Disturbing moments, having frequency components varying over the range from nearly zero to that well beyond the natural frequency of the control, may be encountered. If the system is not critically damped, air gusts having frequency components near the natural frequency of airplane and its automatic control may force abnormal deviations, and what appears to be continuous oscillation results.

The requirement of large static restoring moments imposes the necessity for rate control. The damping provided by rate control limits the angular deviations due to air gusts, and makes possible close automatic control in rough air. If the airplane is subjected to a sinusoidal gust or disturbing moment,

$$M_d=M\sin\omega t$$

the resulting maximum deviation is given by

$$\theta_m=\frac{M}{\sqrt{(C+C')^2\omega^2+[I\omega^2-(K+K')]^2}}$$

A properly proportioned static and rate control together with the airplane's inertia will go far to suppress the deviations throughout the entire range of disturbing frequencies.

For very slow disturbances where ω approaches zero,

$$\theta_{m(\omega\to 0)}=\frac{M_d}{K+K'}$$

and, for the condition of critical damping,

$$\frac{\theta_m}{\theta_{m(\omega\to 0)}}=\frac{1}{1+\left(\frac{f}{f_n}\right)^2}$$

where f_n is the undamped natural frequency. Since the ratio can never exceed unity, the deviations are greatest for disturbances that approach zero frequency. The deviations are mainly limited by the static restoring moment at very low frequencies, by the damping at frequencies near the natural frequency, and by inertia at high frequencies.

The foregoing discussion assumes that control moments proportional to the angular deviation and rate of deviation are applied to the airplane with no time lag between their occurrence and the correcting moments. The measurement of error electrically from a free gyroscope is accurate and instantaneous. The derivation of rate of error from the original displacement error can be obtained electronically with any desired response, depending upon the permissible amplifier gain. However, some time delay is usually present in the process of power amplification and movement of the control surface, principally because of power limitations on the servo unit. Time delay in the application of control moment is important only in relation to the time of response required of the airplane. Where tight control is essential, time delay is usually the limiting factor. Error control, if applied through a system involving appreciable time delay, may cause continuous oscillation, depending upon the damping provided, since the

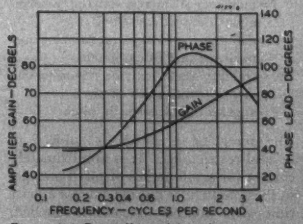


Figure 6. Over-all amplifier phase and gain curves

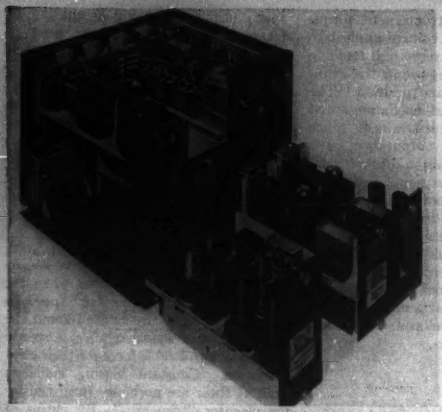


Figure 7. The amplifier rack with removable flight amplifiers

restoring moment then has a component in quadrature (instead of exactly 180 degrees out of phase) with the airplane's angular position, and there is some net energy per cycle supplied to the system. When rate control is applied through time delay, the control moment actually applied to the airplane has a component out of phase with the airplane's angular position. The rate control degenerates partially to error control and the natural frequency may increase considerably, making the need for rate even greater.

If most of the time lag from gyroscope to control-surface hinge moment is concentrated in a single energy-storing system, represented electrically by a series resistance–capacitance network, or mechanically by a viscous friction-spring system, it can be shown that the effect of such lag can be compensated almost completely by the addition of an acceleration or second-derivative signal. The voltage at the input to the servo unit therefore is made proportional to the sum of displacement error and the first and second derivatives of the error.

Error Measurement

Measurement of pitch and roll error is accomplished through the use of inductive "pick-offs" as shown schematically in Figure 3. The primary winding, or center leg, is excited with a 400-cycle voltage. The secondary windings, or outer legs, are connected in series opposing. Angular motion of the airplane with respect to the gyroscope varies the coupling between primary and opposing secondary windings, so that the voltage induced in one secondary winding increases while the voltage in the other decreases. The output voltage is linear with angular rotation and has the phase of the secondary winding with the larger voltage. A curve of pick-off voltage against angular rotation is shown in Figure 3.

This phase-reversing signal pick-off may be described alternatively as a carrier-suppressed or balanced modulator, where the 400-cycle voltage is the carrier and the airplane angular motion is the signal. The carrier is resupplied at the amplifier in the form of a 400-cycle plate voltage to effect "phase detection" or demodulation.

Derivation of Rate and Acceleration Signals

The input signal to the amplifier is a measurement of airplane angular displacement only. This signal is separated into two channels. One channel provides a displacement component, and the other is phase-detected and applied to the differentiating network of Figure 4C. The voltage e_{r_1}, appearing across resistance r_1, is a measure of the time derivative of the demodulated signal voltage e_o. When the single-mesh resistance–capacitance circuit of Figure 4A is considered in more detail,

Figure 8. A-5 automatic-pilot control panel

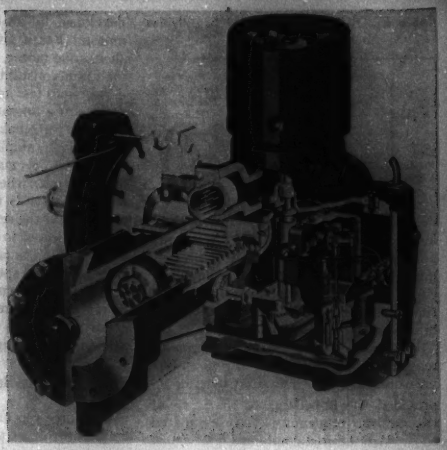


Figure 9. Cutaway view of the servo unit

$$e_o(t) = e_{c_1} + e_{r_1}$$

If $e_{c_1} >> e_{r_1}$, then

$$e_o(t) = e_{c_1}$$

and

$$i = c_1 \frac{de_o}{dt}$$

therefore

$$e_{r_1} = r_1 i = r_1 c_1 \frac{de_o}{dt}$$

If the airplane were hunting at its natural frequency when under automatic control,

$$e_o(t) = E_o \sin \omega_n t$$

and

$$\frac{de_o}{dt} = \omega_n E_o \cos \omega_n t$$

Also,

$$e_{r_1} = \frac{r_1 e_o}{\sqrt{r_1^2 + \frac{1}{\omega_n^2 c_1^2}}} \sin(\omega_n t + \phi)$$

where

$$\tan \phi = \frac{1}{\omega_n r_1 c_1}$$

When r_1 is small compared to $1/\omega_n c_1$, ϕ approaches 90 degrees and

$$e_{r_1} = r_1 c_1 \omega_n E_o \cos \omega_n t = r_1 c_1 \frac{de_o}{dt}$$

Therefore, when the capacitative reactance, x_{c_1}, at the natural frequency of the control system is large compared to r_1, the phase of e_{r_1} is advanced nearly 90

Table I. A-5 Automatic-Pilot Sensitivities in the B-24E

Axis	Control Surface	Pounds Cable Force Per Degree Of Error
Roll	Aileron	40
Pitch	Elevator	48
Yaw	Rudder	63

degrees ahead of e_o. A similar phase lead is possible with a series resistance and shunt inductance, but at these frequencies the large reactance required for effective vacuum-tube operation makes the physical size of the inductance prohibitive.

If we refer to Figure 4B, by the same reasoning e_{r_2}, the voltage across r_2 is a measure of the second derivative of e_o, provided the impedance $\sqrt{r_2^2 + x_2^2}$ at the natural frequency is large compared to r_1. Any desired combination of de_o/dt and de_o^2/dt^2 is obtained by shunting C_2 with the resistance r_3 as in Figure 4C. Phase curves for the network of Figure 4C and measured phase and gain curves for the rate channel of the amplifier are shown as a function of frequency in Figure 5. With r_3 short-circuited, the phase lead approaches 90 degrees at zero frequency, and with r_3 open-circuited the phase lead approached 180 degrees at zero frequency. Phase and gain curves for the entire amplifier are shown in Figure 6.

Servo Unit

The amplified displacement and first- and second-derivative voltages are impressed across the input terminals of the servo unit, or power unit. The servo unit is a self-contained electrohydraulic system which applies cable force proportional to amplifier-output voltage. A hydraulic-pressure repeat-back is incorporated in the servo unit whereby the hydraulic pressure developed in the cylinders, acting across a small valve-stem area, is matched against the force developed by an electromagnetic torque motor. For a given voltage applied to the torque motor, the servo unit tends to maintain constant pressure in the cylinders, regardless of drum position. The servo drum operates at maximum speed until the force balance is attained. Since for a given amplifier output the servo unit tends to maintain a proportional force output, when no signal voltage is applied, it tends to maintain zero force output, and the servo drum moves freely when subjected to external forces. While the servo unit is capable of providing the large forces and speeds required, the average power drawn from the airplane's power supply is kept at a minimum, because pressure is developed only when called for by the signal.

Force Repeat-Back

The force repeat-back principle of aircraft control, as provided by the servo unit, merits some discussion as to the reasons for its use. The aerodynamic force acting on a control surface depends upon the angular deflection of the surface from its neutral or weather-vane position. Neglecting the small positive and negative damping forces acting on the surface because of its rotation and rotation of the airplane, this force is proportional to the surface deflection for small angles. If the airplane's cable-system friction is neglected, therefore, the surface force, hinge moment, and cable force are proportional to their respective deflections.

The control-system frictional forces normally are kept small in order that the human pilot may retain the "feel" of the airplane. Satisfactory manual control is obtained when the ratio of aerodynamic force to friction force is high. The principal load on the control cable therefore may be considered that of a spring. The zero point of the spring, however, shifts over a wide range, depending upon power, loading, and any unsymmetrical conditions which may arise. The spring stiffness is not constant but increases as the square of the air speed. A given force applied to the control cable will result in different deflections of the surface depending upon the air speed, but will result in a fixed control moment independent of air speed. When the servo member of the automatic pilot is made to exert a force on the control cable proportional to error signals, tight control may be retained throughout a large speed range.

Automatic Trim

When the center of gravity of an airplane shifts longitudinally, or when the propeller thrust or the air speed is changed, moments are created about the transverse axis which require a steady elevator-control-cable force for their compensation. Constant biasing moments such as these are normally furnished by the elevator "trim tab." By means of the tab the elevator is shifted to a new angular position, reducing the elevator-cable force to zero. Since the control-surface position at which zero resultant control moment occurs is variable, it is convenient that the servo force be independent of servo position.

Automatic operation of the trim tab in a manner to maintain the average servo-force zero is provided only in the elevator system, where frequent changes in trim occur. The trim-tab control responds to the average elevator servo force, and hence to the average pitch error, θ. The restoring moment provided by the trim-tab control is approximately proportional to the time integral of the pitch error. The total restoring moment about the transverse axis is then

$$M_r = \int \theta dt + K'\theta + C'\dot{\theta}$$

Control of Altitude and Course

When constant altitude is required, the pitch attitude, and hence approximately the rate of climb or descent of the airplane, is varied according to the alti-

Figure 10. The constant-altitude control

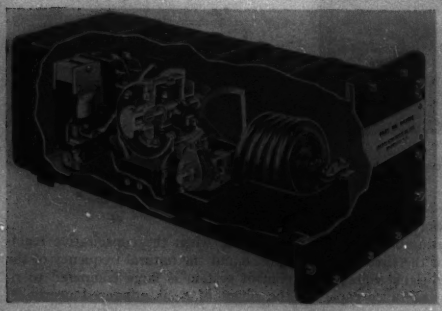
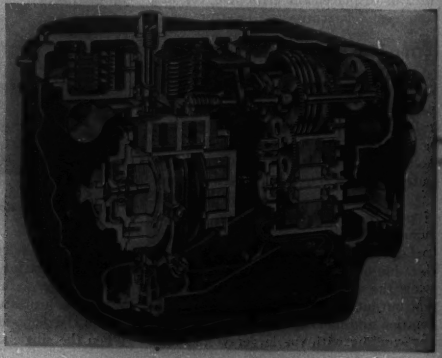


Figure 11. Cutaway view of the azimuth gyroscope



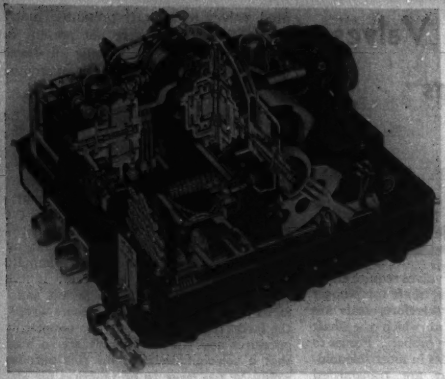


Figure 12. Cutaway view of the vertical gyroscope

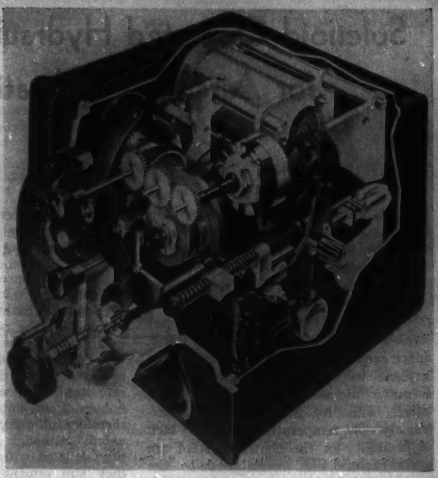


Figure 13 (right). The turn control

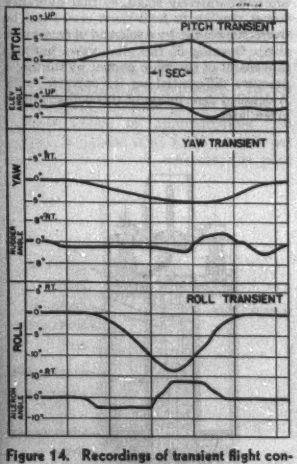


Figure 14. Recordings of transient flight conditions in the *B-24E*

Altitude 6,500 feet; indicated air speed 175 miles per hour

tude error. Since the natural frequency of the airplane position about an altitude reference is low compared to the natural frequency of the pitch control, very close control of altitude is possible by using only altitude error signals. Normal sensitivity of the altitude control is one degree of pitch change per 20 feet of altitude error. The altitude reference is a barometric element, and changes in static pressure are caused to modulate an alternating voltage in a way similar to that already described. This altitude-error signal voltage biases the pitch signal to provide the required changes in pitch attitude. Figure 10 shows a cutaway drawing of the altitude control.

The airplane is maintained on course by setting in heading changes according to departures from some reference on the ground. Heading changes may be very small or may consist of turns of more than 360 degrees. For this reason, heading errors are measured by a synchronous signal transformer, the stator of which is driven from the vertical ring of the azimuth gyroscope. The stator windings of this signal transformer are connected to the stator of an identical unit in the turn control, the rotor winding of which provides the heading-error signal. Either rotor may be rotated to shift the azimuth index, thereby effecting a change in heading. The airplane is automatically banked by shifting the roll index an amount corresponding to the rate of change of heading or rate of turn. The airplane responds quickly to a change in azimuth index, for the control moment provided by the rudder is proportional both to the amount of index change and to the rate of index change.

Performance

The performance of the automatic pilot is best indicated by giving static sensitivities in cable pull per degree of airplane deviation, and reproducing records of transient flight conditions. A table of sensitivities for a typical installation in a *B-24E* "Liberator" is given in Table I.

The flight records are measurements of attitude error and control-surface position in their correct time relationship. The "flight recorder," in measuring attitude, has a dynamic error of less than one tenth of one degree under these conditions of operation. Surface position is recorded by direct mechanical connection to the cable system.

A transient is put into the system by manually overpowering the automatic pilot, holding this condition until considerable attitude error is established, and suddenly removing the manual effort. Typical transients are shown in Figure 14. In each case there is a relatively long period of approximately constant control-surface deflection while the error is increasing. At the end of this period, the system is freed and the error becomes zero in a relatively short time. In each case the airplane returns to its original attitude in an approximately critically damped fashion. The records show that the damping supplied by the automatic pilot is greatest in yaw, a fact which should be expected since the airplane has its greatest inertia and least damping around its vertical axis.

Conclusions

An airplane may be stabilized accurately about its three rotational axes, provided proper error and error-derivative measurements are utilized. High static restoring moments are applied by the automatic pilot with sufficient derivative control to provide approximately critical damping. The static resorting and damping moments supplied by the automatic pilot, together with the airplane's inertia, effectively suppress the deviations over the full range of disturbing frequencies due to rough air. The force repeat-back system permits tight control over a wide range of air speeds and provides a convenient method of automatically maintaining elevator trim.

Solenoid-Operated Hydraulic Valves for Aircraft Applications

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DURING the past several years there has been a definite trend by some aircraft manufacturers to eliminate hydraulic controls from combat airplanes. The vulnerability of hydraulic systems used on airplanes manufactured during this period and to a certain extent today are big factors in promoting this trend. Space requirements in the cockpit of an airplane to mount control valves and accommodate necessary piping to these valves, difficulty with packings at extremely cold temperatures, and the lack of flexibility of the control system are other factors that contributed to the aforementioned trend.

The changeover, however, has been slow because hydraulically operated controls have a number of advantages over other types in applications where considerable work must be done during a short period of time.

As soon as the shortcomings of the standard hydraulic systems relative to combat airplanes became apparent, considerable effort was applied to overcome them. Improved packings for low-temperature operation, hydraulic fuses that isolate any portion of a hydraulic system that has a ruptured hydraulic line, and lightweight solenoid-operated control valves, the advantages and description of operation of which will be given in detail later, are all recent developments that should bring about further consideration of hydraulic controls in applications in which considerable power is required.

Some of the major advantages of solenoid-operated valves are as follows:

1. Manually operated valves require either a rotary or reciprocating shaft for plunger or poppet actuation; therefore, seals are required at the point at which the shaft protrudes from the valve proper. Forces to move poppets or plungers in most solenoid-operated valve designs are transmitted into the valve without any mechanical linkage from outside the valve proper; therefore, all except static seals are eliminated. Although considerable work has been done on hydraulic seals in recent years they still present a troublesome service problem because of deterioration and wear.

2. Manually controlled valves must be accessible; therefore, they are mounted at the control point, such as the cockpit of an airplane. A visual inspection of the control panel of an airplane will show a maze of dials, buttons, and levers on the front side of the panel, and an even greater maze of wires and hydraulic piping at the rear. A solenoid-operated valve may be actuated by a simple switch on the control panel and may be placed in a position that permits short hydraulic line lengths. The total weight and vulnerability of the system consequently are greatly reduced.

3. Since solenoid-operated valves are electrically controlled, they lend themselves to semiautomatic and automatic operation. This feature is of particular importance in combat airplanes where automatic operations will relieve the pilot of at least some mental and physical effort. Automatic operations in which solenoid-operated valves are used are now under test by the Army Air Forces.

Although solenoid-operated valves have been used rather extensively in manufacturing processes and machinery, they are comparatively new in aircraft applications. The application of solenoid-operated valves to aircraft presented many new problems that were not present in previous applications. Some of these problems and means used to overcome them are as follows:

1. Plungers on plunger-type valves may be pressure balanced, so that they can be moved relatively easy, but these valves are difficult to make with leakage rates low enough to be acceptable to the aircraft industry. The leakage rate of a plunger-type valve also increases with usage as the plunger and valve body wear, even if it is hand fitted or lapped to give a low rate of leakage initially. Poppet valves eliminate the leakage objection; however, if the poppets are large enough to permit satisfactory flow at permitted pressure drops, the forces required to unseat the poppets at pressures now used in aircraft are so high that a solenoid designed for this purpose would be too large to be practical for aircraft usage.

2. To bring the forces required to operate poppet valves within reasonable limits, pilot valves are used. Pilot valves are also poppet valves, but port areas of these valves are comparatively small, so that hydraulic forces tending to hold them closed can be overcome readily by a solenoid of reasonable size. Opening of the pilot valve initiates movement of the main poppet by causing a pressure differential on its opposite ends. A detailed description of this action will be given later.

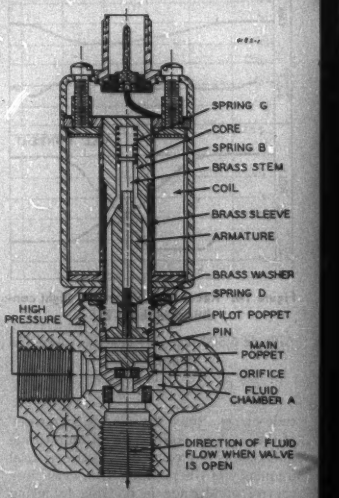

Figure 1. Solenoid-operated normally closed two-way hydraulic valve

A valve of this type weighing approximately one pound will function continuously at pressures as high as 2,000 pounds per square inch. The solenoid will draw one ampere at 24 volts. At a flow of five gallons of AN-VV-O-366b fluid per minute the pressure drop will be 20 pounds per square inch

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When a satisfactory method of angular control is established, the control of altitude and course according to any desired reference is readily attained.

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3. The development of hydraulic oils with comparatively flat viscosity curves also has promoted the use of pilot-operated valves. Pilot operation of valves depends on pressure differentials brought about by opening at least one orifice to permit escape of fluid in sufficient quantities to cause a pressure drop. The chamber from which escape of fluid is permitted is also supplied fluid through a small fixed orifice and clearance around the poppet. As temperatures decrease the oils become more viscous, thereby affecting the flow of fluids through the orifices and clearances, which in turn affects the differential in pressure used to move the main poppet. However, if the viscosity can be kept within reasonable limits the temperature range in which the valve will function satisfactorily is adequate.

A solenoid-operated hydraulic valve design that has proved quite satisfactory is shown in Figure 1. This design is a pilot-operated poppet type. With reference to Figure 1, this valve functions as follows:

We will assume that the valve is closed with fluid under pressure in fluid chamber *A*. Fluid in the space above the main poppet, pilot poppet, and armature also will be under pressure, since this space is open to chamber *A* through the orifice in the main poppet and clearance around the pilot poppet and armature. In the valve shown, the main poppet requires a tractive effort of approximately 120 pounds to unseat it at 1,500 pounds per square inch pressure, whereas, the pilot

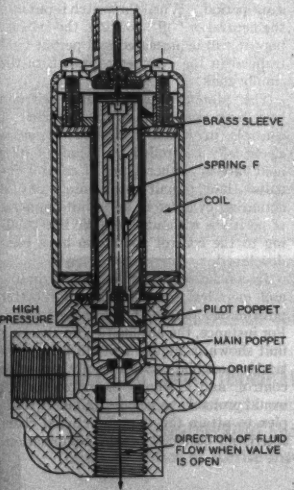


Figure 2. Solenoid-operated normally open two-way hydraulic valve

The size, weight, and functional characteristics of this valve are the same as those described for the valve shown in Figure 1, except that the maximum opening pressure is 1,700 pounds per square inch

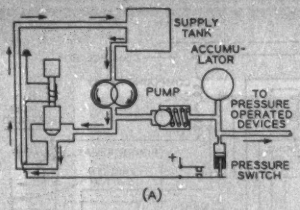


Figure 3. Control circuit for a normally open solenoid-operated valve used as a pressure regulator

A. Solenoid-operated valve in normal position. Pump by-passing fluid at no pressure

B. Solenoid-operated valve in energized position. Pump-filling accumulator

poppet requires a tractive effort of only three pounds to unseat it at this same pressure.

When the coil is energized the armature will move along the brass stem away from the brass washer at the bottom toward the core. During movement of the armature, spring *B* is compressed. At a point where the air gap between the armature and the core is slight, the armature strikes an annular shoulder on the brass stem attached to the pilot poppet and unseats it. Unseating of the pilot poppet permits escape of fluid from the space above the main poppet. Although a small amount of fluid flows into the space above the main poppet through the orifice shown, the pressure drop in this space will be sufficient, so that the high pressure on the area below the main poppet will move it upward. The armature then will be in direct contact with the solenoid core. Spring *B* which was compressed during initial movement of the armature, then will move the brass stem attached to the pilot poppet upward. The pilot poppet which is attached to the main poppet by means of a pin that permits approximately 0.040 movement between them picks up the main poppet and opens it wide. Spring *C* is comparatively light, and spring *B* must be stronger than spring *D* so as to permit full opening of the main poppet. The total time required for opening this valve is less than one-tenth second at normal temperatures.

When the coil is de-energized spring *D* will seat the large poppet and spring *C* will seat the pilot poppet.

Figure 2 shows a valve of similar design except that it is open in the unenergized position. When the coil is energized the armature moves downward, compressing spring *F*. As the armature moves downward it seats both the pilot poppet and main poppet. When both poppets are seated there is a gap between the armature and the head of the brass stem on which the armature slides. When the coil circuit is opened spring *F* moves the armature upward. The force of spring *F* and the impact force of the armature then will open the pilot valve. The maximum opening pressure of this valve is dependent on spring *F*. Sequence of operations to open the valve fully from this point are the same as those described for the normally closed unit.

The impact feature built into these valves adds approximately 30 per cent to the maximum pressures at which these valves open.

Various combinations of two-, three- and four-way valves with ports normally open, normally closed, or a combination of normally open and normally closed can be manufactured to fit any particular application.

Some typical circuits that may be used to control the operation of these valves are shown in Figures 3 and 4.

Figure 3 shows a normally open solenoid-operated valve, same as that shown in Figure 2, used in conjunction with a pressure switch to regulate the flow of fluid to a hydraulic accumulator. A snap-action switch with a slight range of travel between the "off" and "on" position, for instance, might keep the accumulator charged to a pressure of from 800 to 1,000 pounds per square inch. Pressure switches of this type are now available.

Figure 4 is a schematic drawing showing a three-way valve with a normally closed pressure poppet and a normally open exhaust poppet used to charge automatically a gun of the 0.50-caliber *M*-2 Browning type. This system will automatically charge a gun, when it fails to fire, if the trigger switch is depressed. It also provides means to "safety" the gun, that is, hold the bolt in the retracted position so that it cannot be fired.

The hydraulic system, with the exception of the three-way valve, is common to all airplanes that have hydraulic systems. The trigger switch, firing solenoid, and firing relay are common to all airplanes having an electrical firing control.

Three relays and an electrolytic condenser are required in the control box. One control box is required per gun. A normally open switch, that is, actuated by the gun bolt, is mounted on a hydraulic actuating cylinder mounted on the gun.

Any number of guns may be controlled from one common switch in the cockpit; however, a control box, hydraulic actuating cylinder, gun switch,

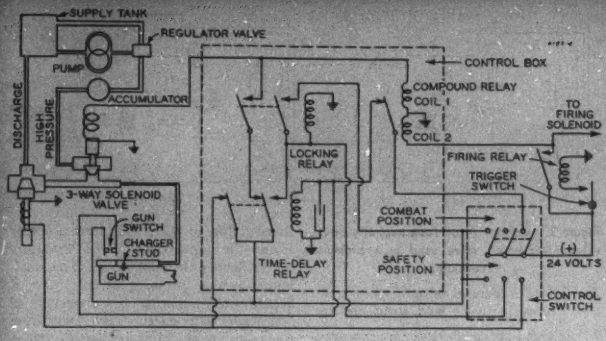


Figure 4. Control circuit for a fully automatic gun-charging system plus means to "safety" guns

and three-way valve are required for each gun.

When the control switch is placed in the "combat" position the time-delay relay is energized by a closed circuit through the control switch and the normally closed contacts of the compound relay. The normally open set of contacts that controls the locking relay coil therefore is closed, the locking relay coil energized, and its normally open sets of contacts closed. The only purpose of the locking relay is to prevent a partial charging cycle when the combat switch is closed initially. From this point on the locking relay will be energized until the setting of the control switch is changed. The two sets of normally closed contacts of the time-delay relay that control the coil circuits of the valve are then open. The system will stay in this condition until the firing switch is closed.

When the trigger switch is closed, coil number 2 of the compound relay is energized, thereby opening its contacts and breaking the circuit to the time-delay relay coil. The normally closed contacts of the time-delay relay will not close immediately because of the condenser across its coil. If the gun then fires, the charger stud will actuate the gun switch once per round fired, thereby maintaining the time-delay relay in the energized state with current impulses. If the gun fails to fire after a predetermined time interval, the two pairs of normally closed contacts of the time-delay relay will be closed and both coils of the valve energized. The exhaust port of the valve then will be closed and the pressure port open. Fluid under pressure is then free to flow into the actuating cylinder which retracts the bolt to its fully recoiled position. In the latter position the gun switch will be made, thereby closing the circuit to the time-delay relay which opens the circuits to the solenoid coils of the valve, which again

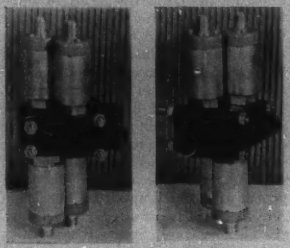


Figure 5. Solenoid-operated four-way hydraulic valve commonly used to control a double-acting cylinder

Weight—4¼ pounds. Will handle flows up to six gallons per minute at a maximum pressure drop of 35 pounds per square inch

assumes its normal position and permits the fluid in the actuating cylinder to return to the supply tank. A quick release mechanism on the charging cylinder holds the gun bolt in the recoiled position and keeps the gun-switch circuit closed until fluid in the actuating cylinder is very nearly exhausted. If the gun does not fire again in the predetermined time after completion of a charging cycle, the operation will be repeated if the firing circuit is still closed.

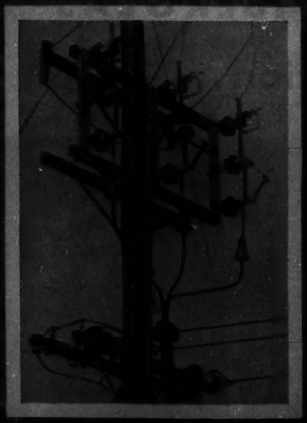
Relay-coil number 1 of the compound relay assures completion of any charging cycle that is initiated, irrespective of the condition of the firing trigger. This coil is hooked into the coil circuit that controls the high-pressure poppet and can be opened only when the gun switch is made at the end of the actuating-cylinder travel.

When the control switch is placed in the "safe" position, the locking relay is immediately energized, and, since the contacts at the time-delay relay are closed, the coil that controls the high-pressure poppet will be energized to unseat it and permit fluid under pressure to flow into the actuating cylinder. The circuit to the coil that controls the exhaust poppet is closed directly as the control switch is put into the "safe" position and, therefore, will remain seated as long as the switch is in this condition. As the actuating cylinder retracts the gun bolt, it will make the gun switch at very near the end of its travel. Closing of the gun switch will energize the time-delay relay coil, the contacts of which will open and break the circuit to the coil that controls the high-pressure poppet which will then seat.

Since the coil that controls the exhaust poppet remains closed as long as the control switch is in the safe position, the gun bolt will be held retracted during this same period. When the switch is put into the neutral or "off" position, the exhaust poppet will be unseated and permit fluid trapped in the cylinder to return to the supply tank.

The aforementioned control circuits have been cited to show the flexibility of controls in which hydraulic power is electrically controlled by means of solenoid valves. Other types of control circuits that permit positioning of an actuating cylinder in an infinite number of positions without hydraulic lines leading to the control point also have been developed.

In conclusion, a combination hydraulic and electrical control may offer better possibilities than either one used alone. For instance, the automatic gun charging unit shown in Figure 4 would be a practical impossibility with a wholly hydraulic control, and a wholly electrical control would probably be heavier and more complex to attain the same functional characteristics obtained by the combination.



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6. Fiberglas base laminated material.
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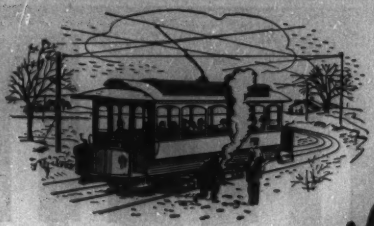

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Report on
NATVAR #400
a New Extruded Plastic Tubing

Excerpts from the E.T.L. report covering tests made on Natvar No. 400 in accordance with A.S.T.M. Standards.

DIELECTRIC STRENGTH — A.S.T.M. D350-42
Average volts per mil: At 28°C — 1090
At 85°C — 700
Wall thickness: .0235"

DIELECTRIC CONSTANT AND POWER FACTOR
Dielectric constant at 29°C and relative humidity 60%
At 60 cycles: 8.15
At 1 megacycle: 4.35
Power Factor: At 60 cycles: .056
At 1 megacycle: .064

ARC RESISTANCE — A.S.T.M. D495-42
Average — 135 seconds

OIL RESISTANCE — A.S.T.M. D295-43T
"Turbol 10" at 105°C was used. After 15 minutes immersion there was no apparent change in the tubing. After 24 and 48 hours there was no sign of change in the tubing. Three separate tests were made.

HEAT ENDURANCE — A.S.T.M. D350-43
After 7 days at 125°C the tubing did not crack or otherwise fail when bent 180° around a $\frac{1}{8}$" mandrel.

TENSILE STRENGTH AND ELONGATION
At 200% elongation: Average 1980 lbs. per sq. in.
At Maximum: Average 2870 lbs. per sq. in.
Total elongation: 350%

LOW TEMPERATURE FLEXIBILITY
After 3 hrs. at minus 30°F specimens were bent around a mandrel $\frac{1}{8}$" in diameter. There was no sign of cracking or other failure.

FLAME RESISTANCE — D350-43
Burned about $\frac{1}{4}$ in. in 10 to 15 seconds and then went out. Three tests were made.

EFFECT OF CHEMICALS
Effect of 7 days immersion in solvents at room temperature; average of 3 tests in each solvent:

Solvent	Change in weight Per cent of weight of specimen as received	Change in dimensions Per cent of dimensions of specimen as received Length	Outside diameter	Thickness
5 per cent sulfuric acid	+ 0.41	none	none	none
1 percent potassium hydroxide	+ 0.83	none	none	none
Petroleum	+ 6.62	+2.6	none	none
Ethyl Alcohol	+ 1.66	none	none	none
Benzol	+21.9	+6.6	+10.9	−24.0

WATER ABSORPTION
Average of 5 tests

Water absorption, per cent by weight of dry specimen	0.63
Soluble matter, per cent by weight of dry specimen	0.01
Total water absorption, per cent by weight of dry specimen	0.64
Change in dimensions: in length	none
in outside diameter	none
in thickness	none

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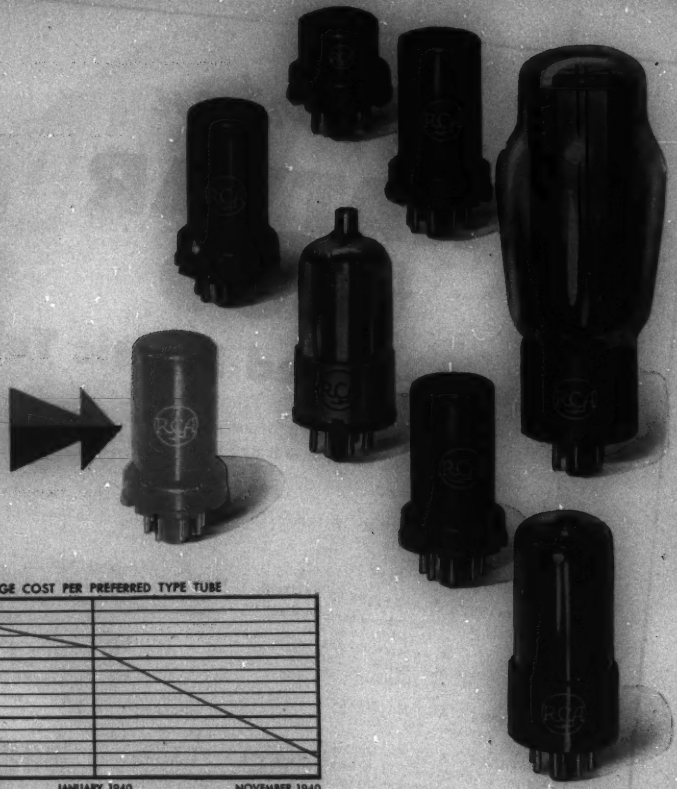

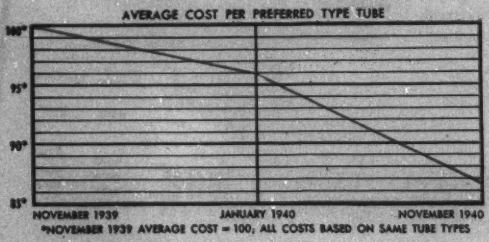

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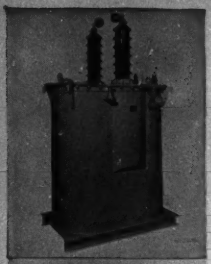

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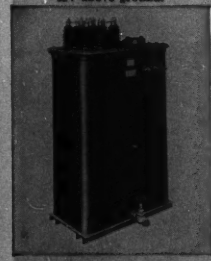
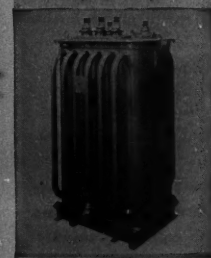


60 KVA, three phase, 60 cycles, 211 volts, Delta primary, 3900 / 6755 / 7800 / 13510 volts Wye secondary.



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Fourth because of the saving that can be made through the elimination of other components.

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Sixth because the users of your products will get greater satisfaction from trouble-free service.

This particular transformer is rated at 6.3 volts, 17VA output and is designed primarily for the stabilization of vacuum tube filament and heater voltages. Other voltages and capacities for chassis mounting can be supplied on the same low cost, economical basis to meet your exact requirements.

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46 Kv. gas filled pothead for gas-filled cable.

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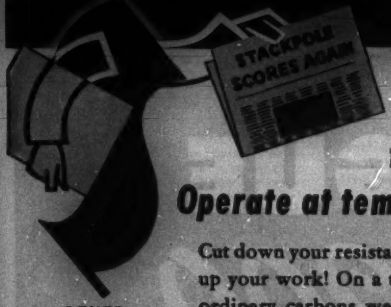
POTHEADS — BOXES — OIL FUSE CUTOUTS — SUBWAY OIL SWITCHES

RESISTANCE WELDING OR
BRAZING CARBON ELECTRODES

THAT LAST 3 to 4 TIMES AS LONG!



Reduce dressing time by two-thirds!

Operate at temperatures above red-heat!

Cut down your resistance welding or brazing costs! Speed up your work! On a typical high temperature job where ordinary carbons were changed hourly, Stackpole Carbons processed with our new "F" treatment lasted all day! Three to four times longer life on the average elevated temperature job is an extremely conservative estimate of the saving involved. And they require dressing only about one-third as often!

Samples for test will gladly be sent to large users who request them on their company stationery. Available in any shape or size.

OTHER STACKPOLE PRODUCTS

Brushes—Contacts (All carbon, graphite, metal and composition types)
Welding Carbon Products
Packing, Piston, and Seal Rings
Battery Carbons
Voltage Regulator Discs
Powder Metallurgy Components

WRITE FOR SAMPLES

State shape and size required.
Mention company connection.

STACKPOLE CARBON CO., ST. MARYS, PA.

STACKPOLE

"EVERYTHING IN CARBON BUT DIAMONDS"

ANNOUNCING*

SPRAGUE

Cerroc 200

A high-temperature (200° C.) ceramic insulation for copper, nickel, and other wire

"We use the word "Announcing" advisedly. Although this is its first public announcement, Sprague CEROC 200 is by no means a new or untried development. Many engineers are already familiar with it. Many have long been using it on restricted war developments on which details cannot yet be announced. So far-reaching are its possibilities for such a wide variety of electrical products, however, and with our production facilities being steadily and materially expanded we take this means of bringing it to general trade attention.

†T. M. REG. U. S. PAT. OFF.

Ceroc 200

INORGANIC INSULATION FOR COPPER AND OTHER WIRE

PERMITS 200° C. CONTINUOUS OPERATION

FOR MANY TYPES OF ELECTRICAL EQUIPMENT

A CLASS C INSULATION MATERIAL

CROSS SECTION The extreme uniformity of CEROC 200 makes for smooth, level winding. The thinness with which it may be deposited on the wire saves space.

Culminating seven years of continuous research and development by the Sprague engineering organization, CEROC 200 now paves the way for greatly increased efficiency, smaller sizes, and lighter weight for a wide variety of electrical equipment.

Sprague CEROC 200 is a ceramic (inorganic) insulating coating thinly deposited on copper, nickel, and other types of wire, and permitting much higher continuous operating temperatures than are possible with ordinary Class A insulations such as enamels, varnishes, and other organic materials. Applied to copper wire, it permits of a conservatively rated 200° C. continuous operating temperature as compared to the present limit of 105° C. for Class A materials. Thus, by designing electrical equipment to utilize the full maximum operating temperature of this new wire coating, a very substantial increase in volt-ampere rating can be obtained. We believe that CEROC 200 meets all requisites of a Class C insulating material under A. I. E. E. standards.

THERMAL CONDUCTIVITY: Coils wound with CEROC 200 dissipate heat rapidly. There is little or no tendency toward development of hot spots which might nullify a big percentage of the high-temperature gain that would otherwise be expected. Thus, the high-temperature advantages of CEROC 200 are real and not apparent.

SPACE FACTOR is extremely good. Typical percentages of copper area to total cross-sectional area of finished wire are 96% for AWG #21 wire, and 95% for #24 wire for CEROC 200 by comparison with only 69% and 59% respectively for other insulations that might be used for high-temperature applications. Moreover, CEROC 200 coating is extremely uniform, thus making for smooth, level winding. The preferred coating thickness is ¼ mil., and the following characteristics are based on wire so coated:

MAXIMUM STABLE TEMPERATURE for continuous operation—200° C.

VOLTAGE BREAKDOWN between two wires of a twisted pair 4" long:

Standard condition (25° C.)—300 v. A.C.

Humid condition (95% relative humidity)—300 v. A.C.

Hot condition (200° C.)—300 v. A.C.

LEAKAGE between two wires of a twisted pair, 4" long, at 95% relative humidity is greater than 100,000 megohms.

FLEXIBILITY by bending: 16% elongation.

ABRASION RESISTANCE: Average 16-18 scrapes at 200 G. weight on G.E. abrasion tester for #25 AWG wire having the preferred ¼ mil coating thickness. On wire sizes smaller than #25, this average is slightly less, and on larger than #25 wire, it is somewhat more.

WIRE SIZES: Although CEROC 200 is constantly being adapted to new uses, the present preferred ranges for coated wire are as follows:

Copper wire—from 3 to 30 mils (#40 to #21 AWG).

Nickel wire—from 1½ to 12 mils (#46 to #28 AWG).

WINDING CHARACTERISTICS: CEROC 200 is sufficiently flexible to present no winding difficulties that will not be far more than compensated for by its tremendous high temperature and space advantages. In general, round coils can be wound satisfactorily by existing methods. Slight modifications in winding technique may prove necessary, however, in the case of rectangular coils or motor armatures.

Although costs on CEROC 200 are being steadily revised downward, as a result of greatly increased facilities, it should be borne in mind that this material was not designed to compete on applications where conventional organic insulations are giving satisfactory service. Rather, it is intended for those applications where a substantially higher temperature insulation combined with space- and weight-saving factors more than justify a somewhat higher price for the CEROC 200 insulation that makes them possible.

SAMPLES

CEROC 200 is by no means a new or untried development. For more than a year, large quantities of CEROC-insulated wire have been supplied for important war applications of the most exacting sort. Thus, although production facilities are being steadily increased, it is still difficult to supply generous samples of specific wire sizes to all who might be interested. As far as possible, however, we will gladly supply small quantities of available sizes to large users who want to test its far-reaching possibilities in connection with their products at a later date when full and prompt deliveries are possible.

SPRAGUE ELECTRIC COMPANY, North Adams, Mass.

(Formerly Sprague Specialties Company)

SPRAGUE

CAPACITORS • KOOLOHM RESISTORS • CEROC INSULATION

†TRADEMARKS REGISTERED U. S. PATENT OFFICE

CORNELL-DUBILIER pioneers its designs on the drafting board of experience

Through the years, Cornell-Dubilier has keyed its design to the needs and requirements of the radio and electronic industries.

When the accelerated demands of war came, C-D was prepared with the experience, the skills and the equipment needed. For 34 years C-D research engineers have been active partners with equipment manufacturers. To supply their requirements, C-D has expanded from one plant in 1940 to six plants today.

The tremendous increase in production has not affected the high quality of C-D Capacitors. Their inherent stamina has been battle-tested in countless war applications. The finest materials, the same care thru every step of construction, produces the dependability which makes C-D's the choice of 4 out of 5 engineers. Consult us in the design stages of your product, we will gladly contribute our knowledge and experience.

Cornell-Dubilier Electric Corporation, South Plainfield, N. J.

C-D HIGH POWER TRANSMITTER TYPE 59

For use as grid, plate blocking, coupling, tank and by-pass applications in high power transmitters. Low-loss, glazed ceramic cylindrical case. Can be mounted in any position. Series or parallel combinations obtained by bolting terminal ends together. Send for details.

Cornell-Dubilier Capacitors

MICA • DYKANOL • PAPER • WET AND DRY ELECTROLYTICS
WORLD'S LARGEST MANUFACTURER OF CAPACITORS

"FRAHM" *Resonant Reed* INSTRUMENTS

Frahm Frequency Meter with one row of 101 reeds. A recent development for a government agency.

NEW MODELS ... *New Applications*

The resonant reed principle as applied to the measurement of speed, frequency and rates of vibration, first introduced in this country by Mr. James G. Biddle in 1910, has been widely adopted for a variety of services. During recent years, we have been called upon to develop units for special applications far removed from the original simple measurements of speed and frequency. Some of these special purpose instruments are shown here; some have already been standardized for regular production.

We invite correspondence regarding problems that may be solved through measurements of frequency and rates of vibration. Our accumulated experience in the development and use of Frahm Resonant Reed Instruments should prove of value in suggesting an application for your particular requirements.

Write for Bulletin 1755-EE.

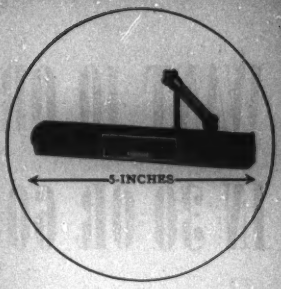
Frahm Electric Tachometer. A group of reeds in the same range to aid in synchronization of the speeds of 4 engines.

Frahm Portable Frequency Meter for "series" operation in testing a special telegraph circuit.

Frahm Frequency Meter for determining temperatures of salt and fresh water.

Frahm Frequency Meter for use in a special electronic circuit. Used in a device for geodetic surveying.

JAMES G. BIDDLE CO. 1211-13 ARCH STREET PHILADELPHIA 7, PA.



No Fallacious Guesses.

There is no guessing with a Matthews Teleheight. Any lineman can be taught to use it and get any height within an inch or so. He can learn in five minutes.

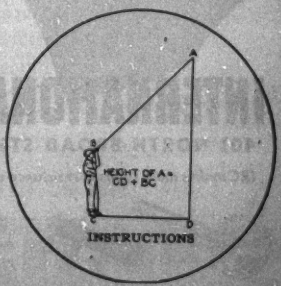
The extra cost of just one wrong guess will pay for one or two Matthews Teleheights. Hundreds of them are saving lots of money for their owners all over the country. Many are being used for quickly figuring the cubical contents of buildings, the clearance of bridges, highlines, etc.

Matthews Teleheight is only five inches long. Has no moving parts. It is furnished with a leather carrying case that will fit in the vest pocket. The drawing below shows how simple are the directions for using it.

Great for Appraisal Jobs.

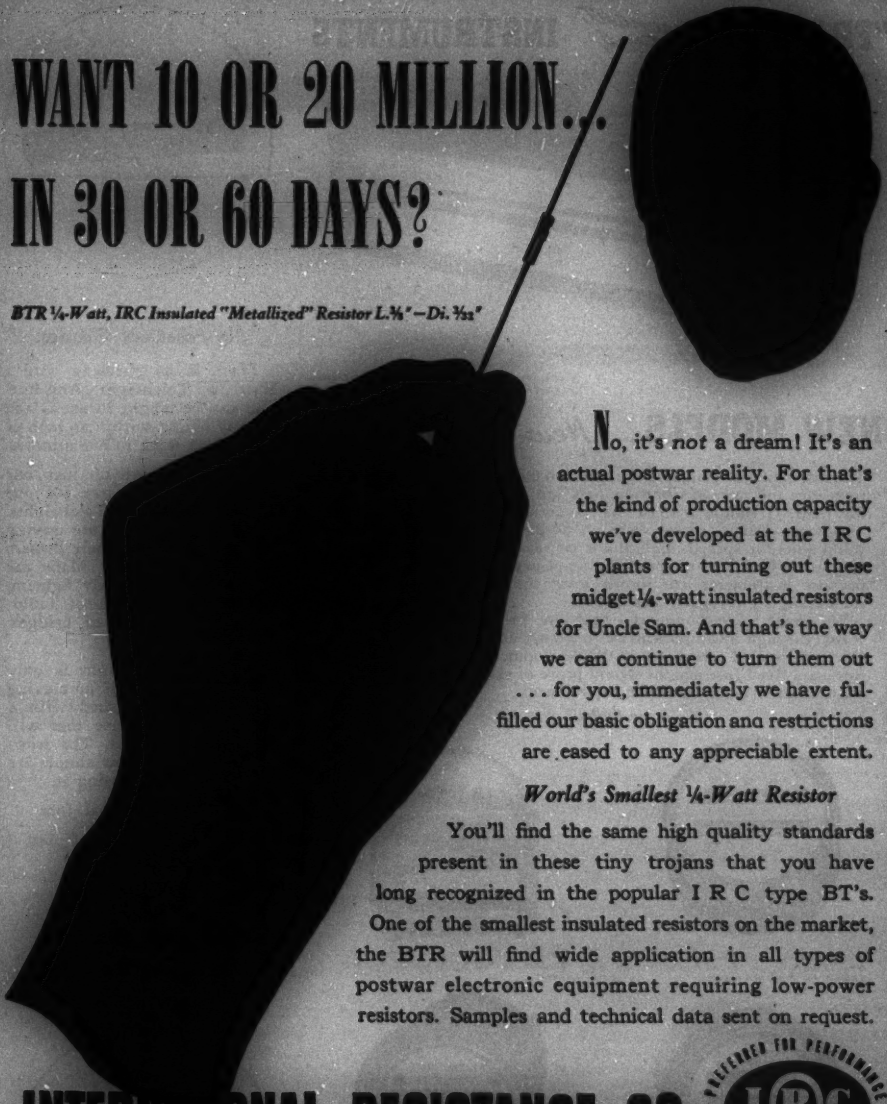
Try one at our risk of your approval.

W. N. MATTHEWS CORPORATION
ST. LOUIS, U. S. A.



INSTRUCTIONS

WANT 10 OR 20 MILLION... IN 30 OR 60 DAYS?



BTR ¼-Watt, IRC Insulated "Metallized" Resistor L.⅛"—Di. 1/32"

No, it's *not* a dream! It's an actual postwar reality. For that's the kind of production capacity we've developed at the IRC plants for turning out these midget ¼-watt insulated resistors for Uncle Sam. And that's the way we can continue to turn them out . . . for you, immediately we have fulfilled our basic obligation and restrictions are eased to any appreciable extent.

World's Smallest ¼-Watt Resistor

You'll find the same high quality standards present in these tiny trojans that you have long recognized in the popular IRC type BT's. One of the smallest insulated resistors on the market, the BTR will find wide application in all types of postwar electronic equipment requiring low-power resistors. Samples and technical data sent on request.

INTERNATIONAL RESISTANCE CO.

401 NORTH BROAD STREET • PHILADELPHIA 8, PA.

PREFERRED FOR PERFORMANCE · IRC · FIXED & VARIABLE RESISTORS

IRC makes more types of resistance units, in more shapes, for more applications than any other manufacturer in the world.

Governor Motor Contactors.
Unit No. 1
To Existing Governor-Motor Control Switches
Unit No. 2
Micromax Recording Controller for tie-line load. Measures tie-line load, and sends correcting impulses to governor-motor contactors when actual load differs from scheduled load.
Unit-Selector Switch. Enables operator to assign tie-line control to any generating unit.

TIED IN WITH A UTILITY?
Here's the Tie-Line Control You'll Need

Industrial power plants which are tied in with a public-utility or other power network much larger than themselves can use the Micromax Tie-Line Load Controller to maintain, automatically, any desired interchange of load, and also to record the amount of power which changes hands. No alterations in the generator-governor are required; the Micromax Load Recorder simply operates the synchronizing motor on the governor, just as a man would do. In addition to being continuous and fully automatic, however, the mechanism detects and acts on load changes while they are still too small to show on a wattmeter, and so the Controller brings a new order of precision to the job of load-regulation.

This Controller is, mechanically, a standard Micromax, like those employed for temperature, frequency, voltage, salinity and many other conditions. Its load detector, the Lincoln Thermal Converter, is also a standard device on public-utility systems; it has no moving parts and requires no maintenance. The whole equipment can be installed by an electrician or instrument man.

If you have a tie-line load problem on which this Controller could apply, outline it and we will send further information.

Jrl Ad N-56-161(3)

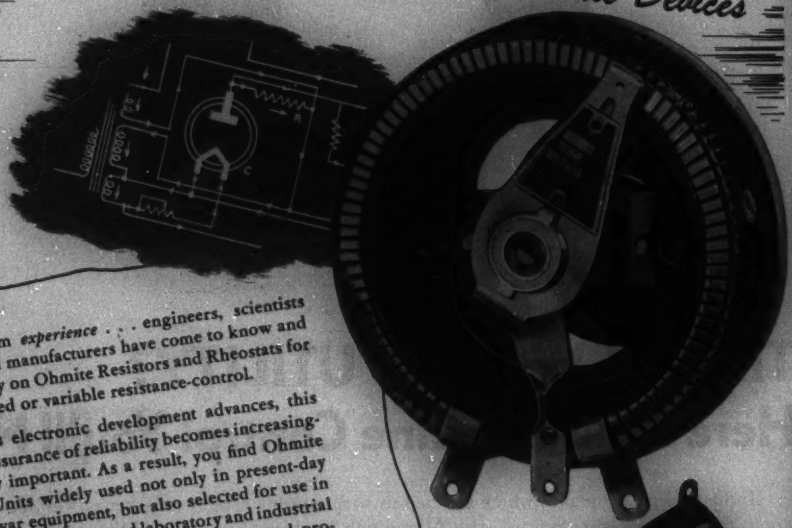
LEEDS & NORTHRUP COMPANY, 4962 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

OHMITE
Rheostats and Resistors

for Dependable Control of New Electronic Devices



From *experience* . . . engineers, scientists and manufacturers have come to know and rely on Ohmite Resistors and Rheostats for fixed or variable resistance-control.

As electronic development advances, this assurance of reliability becomes increasingly important. As a result, you find Ohmite Units widely used not only in present-day war equipment, but also selected for use in the most advanced laboratory and industrial electronic devices designed to speed production, increase operating efficiency, improve product quality.

In resistance-control, Ohmite experience makes a difference.

OHMITE MANUFACTURING CO.
4802 FLOURNOY STREET . CHICAGO 44, ILLINOIS

Write on company letterhead for helpful 96-page guide in the Selection and Application of Rheostats, Resistors, Tap Switches.

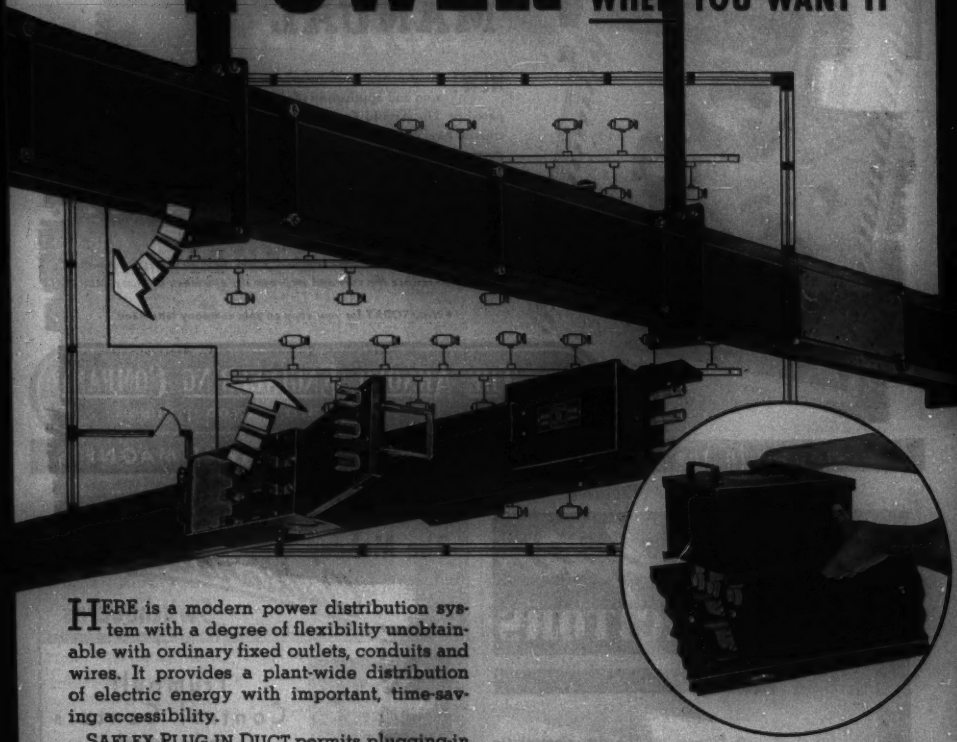
Applications

A few of the advanced electronic devices using Ohmite units:

Electron Microscope
Industrial X-Ray
Electronic Heater
Photo-Electric Control
Mass Spectrograph
Electronic Voltage Regulator
Electronic Motor Speed Control

Be Right with OHMITE
RHEOSTATS • RESISTORS • TAP SWITCHES

POWER WHERE YOU WANT IT WHEN YOU WANT IT



HERE is a modern power distribution system with a degree of flexibility unobtainable with ordinary fixed outlets, conduits and wires. It provides a plant-wide distribution of electric energy with important, time-saving accessibility.

SAFLEX PLUG-IN DUCT permits plugging-in for power service anywhere in the plant. It enables you to add new machines, or rearrange present equipment without the usual major operation on the wiring system. Put a machine where you want it. Your power is available on a moment's notice.

SAFLEX FEEDER DUCT serves as a feeder bus for the branch circuits of Saflex Plug-in Duct, or any other service where a heavy current feeder is needed. Because it has convenient tap connections at frequent intervals throughout its length, it serves as a perfect backbone from which to build complete distribution systems for resistance welder installations.

Call in a Square D Field Engineer

Now is the time to bring your wiring system up to date for the highly competitive future. Address Square D Company, 6060 Rivard Street, Detroit 11, Michigan, for Bulletin 6000. Or let a Square D field engineer help you plan for greater efficiency in electrical power distribution.

SQUARE D COMPANY

DETROIT • MILWAUKEE • LOS ANGELES

Latest Permanent Magnet MANUAL

NEW! A valuable, up-to-the-minute manual on the design, production and application of the modern permanent magnet. Prepared by The Arnold Engineering Company, this is an authoritative treatise based on many years' experience in the production of Alnico permanent magnets for a wide range of applications.

Contents include such subjects as Magnet Materials, Resistance Comparisons, Physical and Magnetic Properties, Demagnetization and Energy Curves, Fabrication, Design and Testing. Charts and tables illustrate and explain various aspects of the discussion.

Recent improvements have opened many new fields for permanent magnets to reduce the cost and improve the efficiency of many devices.

● Write TODAY for your copy on your company letterhead.

THE ARNOLD ENGINEERING COMPANY
147 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS

Specialists in the Manufacture of ALNICO PERMANENT MAGNETS

Electrolytic CAPACITORS

● Pioneering the dry electrolytic capacitor—maximum capacitance in minimum bulk and at low cost—Aerovox continues to offer the outstanding choice of types for initial-equipment and replacement purposes.

In the latest Aerovox catalog intended for engineers, designers and builders of equipment, are to be found many new and previous types meeting all voltage, capacitance, container, terminal and mounting requirements. Motor-starting capacitor replacements are covered in another catalog.

● *Write for Literature. Specify whether for replacement or initial equipment when writing. Submit that problem.*

AEROVOX *Capacitors*
INDIVIDUALLY TESTED

The Makeup of *Outstanding* Switchboards

Trumbull Control Centers make use of ASCO TRANSFER SWITCHES

Trumbull Control Centers are being used in many plants as distribution points for power. They're efficient and reliable . . . not only because of the soundness of the basic design but because of the superiority of the component parts. ASCO Electrically Operated Transfer Switches take care of that important function in Trumbull Centers.

Many companies manufacturing electrical equipment requiring electrically operated Transfer Switches, Remote Control Switches, Contactors and Relays have standardized on ASCO. They have found them efficient and reliable.

INCLUDE:
AUTOMATIC TRANSFER SWITCHES
REMOTE CONTROL SWITCHES
CONTACTORS
RELAYS

We also manufacture a complete line of Solenoid Operated Valves for Automatic and Remote Control of Liquids and Gases

Automatic Switch Co.
41-H EAST 11th STREET, NEW YORK 3, N. Y.
11-AS-6

FOR EXTRA PROTECTION TO WINDINGS

DOLPH'S INSULATING VARNISHES

Today it is most essential that transformers are built to withstand temporary power surges and deliver uninterrupted service. It is a known fact that these power surges can prove to be very detrimental to the varnish insulation on coil windings and will tend to lessen the useful service of your equipment. Large transformer manufacturers such as the Jeffries Transformer Company of Los Angeles are building power transformers of all designs for industry and are guarding against this deteriorating factor by using DOLPH'S Insulating Varnish.

No matter what type of electrical units you manufacture, you will find a DOLPH Insulating Varnish formulated to do a better job by providing the extra protection under severe operating conditions. Why not let us help you with your insulating varnish problems?

The above cut-away photo is a 50 K.V.A. Air Cooled Power Transformer manufactured by Jeffries Transformer Company.

Dolph's

JOHN C. DOLPH COMPANY

Insulating Varnish Specialists

166-8 EMMETT ST. NEWARK, N. J.

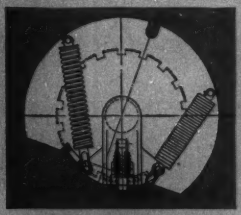
The "Quick-Break" Principle

— IT'S TYPICAL OF THE ADVANCED PRINCIPLES USED IN ALLIS-CHALMERS 5/8% STEP REGULATORS

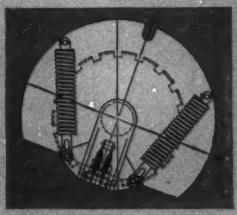
1 **SLOW-BREAK** principle is illustrated by javelin-thrower, who applies energy as it is generated . . . does not store it in advance.

2 **QUICK-BREAK** action results when energy is built up for sudden release. Allis-Chalmers tap-changing mechanism is quick-break *for longer contact life.*

3 **MECHANISM** is shown above with driving motor and gear removed. Drive springs snub the mechanism to a quick stop.



4 **COCKED** by tension on left-hand driving spring, the mechanism in above position is ready to make a tap change.



5 **RELEASED,** the crank arm operates tap-changer switch and is snubbed to stop by springs *without shock to mechanism.*

6 **MOVING CONTACT** is still in good operating condition after equivalent of 50 years in normal service. Fast contact separation and large contact size both contribute to long life.

7 **OTHER PRINCIPLES:**

- All moving parts on Allis-Chalmers 5/8% Step Regulators are oil-immersed . . . remain dust-free and need no lubrication.
- Feather-touch control, coupled with voltage integration, fits regulator to handle wide variation in load conditions.
- Unit construction, with transformer and tap-changing mechanism suspended from cover, eliminates 78 bolted connections.

Write for Bulletin B6056A, ALLIS-CHALMERS MFG. CO., MILWAUKEE 1, WISCONSIN.

A 1795

JUST AROUND THE CORNER

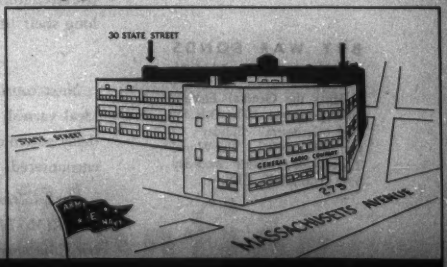
● LATELY, persons corresponding with us have noted a new address . . . . . 275 Massachusetts Avenue. We've moved our engineering and general business offices into a remodeled building at this location. It's just around the corner from 30 State Street, which is still ours, and which is now devoted exclusively to manufacturing.

For a long time we have felt the need for rearranging our space; for one thing we have been badly cramped in the shop; and our engineering department has been spread over several floors and mixed up with many other activities.

The new building, which is connected by ramps on two floors with the older one, provides about 30 per cent more manufacturing space, and allows all of the engineering department to be on one floor.

Under pressure of the war we have expanded our output in several ways. We have let out the manufacture of several instruments to subcontractors; we have turned over the designs, drawings and models of several instruments to other manufacturers for their exclusive use; we have rented considerable extra space in two outside buildings, in one of which we have contracted for a large number of war-time workers under our own foremen.

After the war when the armed guards have left us, we hope that you will come to see our new laboratories and offices. In the meantime we continue to devote our energies to filling war orders for electronic laboratory test equipment.



VARIAC

MADE ONLY BY **GENERAL RADIO COMPANY**

Cambridge 39, Mass.

NEW YORK
CHICAGO
LOS ANGELES

What to Look for Selecting Varnished Cloth

STARCH VS. VARNISH

The first thing to look for when selecting a varnished cloth is the degree of sizing. The more starch used in the sizing process, the less varnish there will be in the finished product — and it's the varnish that insulates, not the starch. G-E varnished cloth contains minimum sizing and maximum varnish impregnation. Heavy sizing produces a "slick" appearing cloth — one that looks "nice". Minimum sizing helps produce a cloth with high dielectric strength, power factor, resistance to moisture, excellent heat aging and long shelf life.

DEGREE OF VARNISH HARDNESS

Next consider the varnish — particularly its degree of hardness. The ideal varnish must be soft enough to retain maximum flexibility and to delay stiffening; yet hard enough to withstand abrasion where it may be encountered.

For additional details consult your local G-E Distributor or write: Section RIM-1141-32, Resin and Insulation Materials Division, General Electric Company, Schenectady 5, N. Y.

BUY WAR BONDS AND KEEP THEM

● Hear the General Electric radio programs: "The G-E All Girl Orchestra" Sunday 10 p.m. EWT, NBC. "The World Today" news every weekday 6:45 p.m. EWT, CBS.

GENERAL ELECTRIC

BAKELITE

MOLDABILITY...

HIGH FREQUENCY RESISTIVITY...

STRUCTURAL STABILITY OF COMPLEX FORMS...

INVISIBLE FIRST WINDINGS

These radio coil forms are molded from BAKELITE low-loss phenolic material. Power factor is .023 at 60 cycles; .010—.014 at 10^6 cycles; and .007—.009 at 10^8 cycles) is practically unchanged after a day's immersion in water. Their dielectric constant at all frequencies is 4.7—5.2. The high volume resistivity inherent in this plastic (above 10^9 megohm centimeters) drops but slightly with increased temperature.

Modern high-frequency radio coil forms are molded from BAKELITE low-loss phenolic plastic. Ribbed spheroids—4 x 5 inches in size, and 13 ounces in weight—these forms have electrical characteristics ideal for use in high frequency circuits below 30 mc. They are also dimensionally stable, resistant to high humidity, and are unharmed by the heat generated in the operation of some equipment.

These radio coil forms show that BAKELITE low-loss phenolic material can be readily molded into complicated shapes. It offers many possibilities for the fabrication of insulating parts designed for high frequency apparatus—always contributing, in addition to its other properties, the advantages of compactness, strength, and light weight.

Investigate this BAKELITE material now—for today's essential requirements and for consideration in your postwar planning. Write Department 5.

TRADE MARK

BAKELITE CORPORATION, 30 E. 42 St., New York 17, N.Y.

Unit of Union Carbide and Carbon Corporation

UCC

Molding Plastics

Simply on the surface

111 XTENSIONDUCT—2 WIRES

333 METAL MOLDING—4 WIRES

888 METAL MOLDING—10 WIRES

711-A FLORDUCT—3 WIRES

733-A FLORDUCT—TWO-26 PAIR

National Electric Surface Raceways for surface wiring are easily installed. They have a neat appearance and may be painted with either oil or water paints to match interiors. These raceways are securely fastened to all fittings. No screw connections necessary. Push tongue connection insures perfect permanent ground. Wires are laid in the base; the capping snaps on. No fishing or tearing up walls or floors.

Write for descriptive literature on "La-in" surface raceways.

Listed and approved by Underwriters' Laboratories, Inc.

National Electric Products Corp.
Pittsburgh, Pa.

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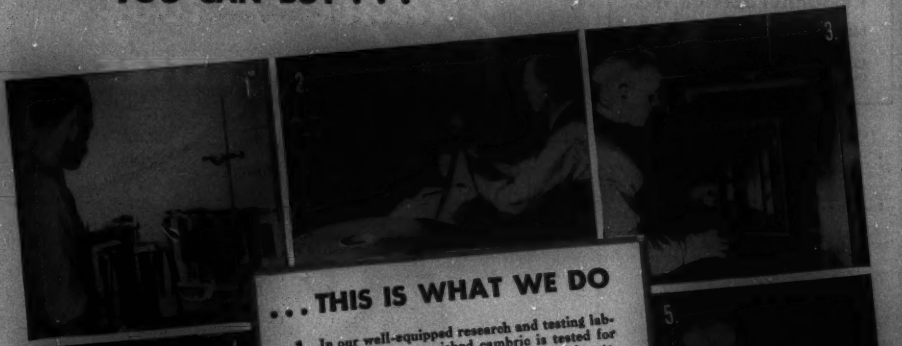

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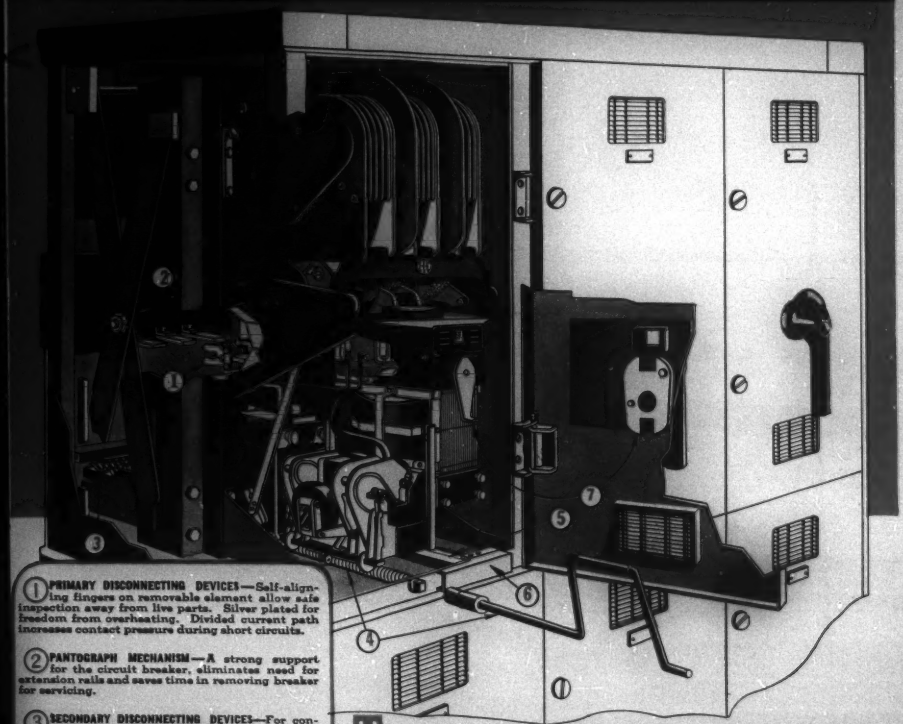

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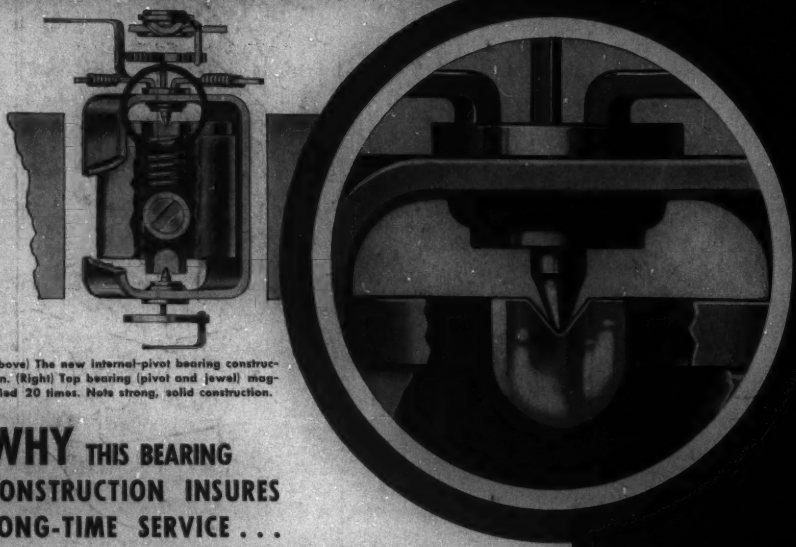

(Above) The new internal-pivot bearing construction. (Right) Top bearing (pivot and jewel) magnified 20 times. Note strong, solid construction.

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